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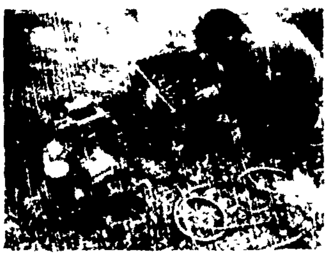

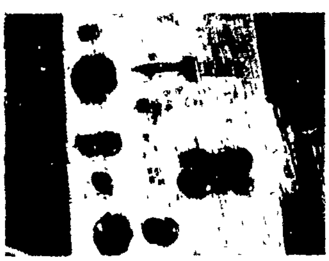

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PHYSICAL EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: PHASE I STUDIES

by

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Baseline data on freshwater mussels (Mollusca:Unionidae) were collected at productive mussel beds in the upper Mississippi River from 1987 to 1989. This study, funded by the US Army Engineer District, St. Louis, was initiated to determine if increased commercial navigation traffic resulting from completion of the Melvin Price Locks and Dam near Alton, IL, would affect freshwater mussels. In 1987-88, a total of 667 incremental qualitative samples were obtained between river mile (RM) 233 and 708, and 10 to 30 quantitative (0.25-m^2) samples were obtained at RM 299.6, 389.5, 409.5, 433.3, 450.4, 504.7, and 635.0. Subsequent intensive sampling (1989-94) will be conducted at a minimum of four beds to determine the effects of commercial navigation traffic on density, relative species abundance, species richness, size demography of dominant species, physical condition, and presence of uncommon or endangered species (especially *Lampsilis higginsi*).

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Cumulative species was related to the logarithm of cumulative individuals; there were no substantial differences in this relationship with respect to RM or sampling technique (qualitative versus quantitative). There were significant differences in total biomass and substantial differences in relative species abundance between nearshore (characterized by comparatively finer sediments, shallower depths, and reduced water velocity) and offshore sites. Total density was higher at four nearshore sites (44.0 $\pm$11.2 to 333.2 $\pm$215.8 standard deviations ($\pm$SD) individuals/m^2) than at four offshore sites (23.6 $\pm$12.7 to 137.2 $\pm$50.6 individuals/m^2, F = 14.24, P = 0.0001). No specific trends in shell morphometrics (shell mass versus shell length and tissue dry mass versus shell length) were apparent with respect to RM, although interpool differences were found.

PREFACE

In accord with the Endangered Species Act, Section 7, Consultation, personnel from the US Army Engineer District, St. Louis (LMS), and the US Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated that would assess the effects of existing and future increased traffic levels on freshwater mussels including *Lampsilis higginsi*. Concern had been expressed by the USFWS and other agencies over projected increases in commercial traffic resulting from completion of the Melvin Price Locks and Dam, Second Lock Project, at Alton, IL (formerly known as Locks and Dam 26). In March 1988, LMS contracted with the US Army Engineer Waterways Experiment Station (WES) to initiate these studies, which are scheduled to continue at least until 1994.

Divers for this study were Messrs. Ron Fetting, Ed Strand, Kenneth Schroeder, and Bob Sikkila, US Army Engineer District, St. Paul (NCS); and Messrs. Larry Neill, William H. Host, Jr., and Johnny Miller, Tennessee Valley Authority. Field assistance was provided by Messrs. Robert Whiting and Barry Drazkousky, NCS, and Mr. Tim Brophy, LMS. Assistance with laboratory and data analysis was provided by Messrs. Tony Denka, Macalester College, St. Paul, MN; Ken Gordon, Jackson State University, Jackson, MS; Carl Way and Maria Ogden-Davis, WES. This report was edited by Ms. Janean Shirley of the WES Visual Production Center, Information Technology Laboratory.

During the conduct of these studies Dr. John Harrison was Chief, Environmental Laboratory (EL), WES, Dr. Conrad J. Kirby was Chief, Environmental Resources Division, EL, and Mr. Edward Theriot was Chief of the Aquatic Habitat Group, EL. Authors of this report were Dr. Andrew C. Miller and Dr. Barry S. Payne, EL; Dr. Daniel J. Hornbach, Macalester College; and Daniel V. Ragland, LMS.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

PHYSICAL EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: PHASE I STUDIES

PART I: INTRODUCTION

Background

1. Operation of the second lock at the Melvin Price Locks and Dam (formerly the Locks and Dam 26 (Replacement) Project) will increase the capacity for commercial navigation traffic in the upper Mississippi River (UMR). Increased commercial traffic could detrimentally affect freshwater mussels (Mollusca:Unionidae), including *Lampsilis higginsi*, listed as endangered by the US Fish and Wildlife Service (USFWS) (1987). In accordance with the Endangered Species Act, Section 7, Consultation, personnel from the US Army Engineer District, St. Louis (LMS) and the US Fish and Wildlife Service determined that a monitoring program should be initiated to assess the effects of existing and future traffic levels on freshwater mussels including *L. higginsi*. Other agencies that participated in the development of this program included the US Army Engineer Divisions, Lower Mississippi Valley and North Central, and the US Army Engineer Districts, St. Paul and Rock Island. State conservation agencies and interested lay personnel also participated.

2. This monitoring program will consist of physical and biological studies to be conducted at five mussel beds in the UMR. The program includes pilot studies during 1988 and part of 1989, baseline studies to be completed in 1994, and comparative studies to be conducted through the year 2040 when commercial traffic is predicted to reach its maximum. This report contains a summary and synthesis of data collected during the first year of this program. The majority of the data were collected in 1988, although qualitative data from two locations (river mile (RM) 635.0 and 708.5) were obtained in 1987 as part of other studies. As of June 1989, three mussel beds have been identified for detailed study beginning in the summer of 1989. It is planned that two additional mussel beds will be identified during the 1989 study year.

Purpose and Scope

Upper Mississippi River

3. The purpose of this program is to monitor community composition and population structure at mussel beds in the UMR where *L. higginsi* is known to occur. In 1989, a decision was made to also conduct studies in Pool 24 where *L. higginsi* has not been found. Results of these studies will be used to determine if and to what extent commercial navigation traffic in the UMR affects *L. higginsi* and other species of mussels. The purpose of the baseline studies discussed in this report was to obtain qualitative and quantitative data and select mussel beds for detailed study. In addition, this information will be part of the larger data set that will be used to evaluate commercial traffic effects.

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PART II: EVALUATING COMMERCIAL TRAFFIC EFFECTS

Physical Effects of Commercial Vessel Passage

4. The continued use of inland waterways to transport bulk commodities (Dietz et al. 1983) has caused many biologists and planners in government agencies to express concern over the possible negative effects of commercial traffic (Upper Mississippi River Basin Commission 1982; Rasmussen 1983; US Fish and Wildlife Service 1986). The physical effects of commercial vessel movement include periods of wave wash, turbulence, benthic scour, drawdown, current reversals, and sediment resuspension (Wright 1982). Freshwater mussels, a resource with economic, ecological, and cultural value, could be affected by these disturbances. Their sedentary lifestyle and reliance on suspended particulate organic matter makes them susceptible to fluctuating water levels, sedimentation, and turbulence. Previous authors have suggested that commercial use of waterways has directly and indirectly contributed to a loss of species richness of freshwater mussel fauna in large rivers (Stansbery 1970; Starrett 1971; Anderson, Sparks, and Paparo 1978; Fuller 1978, 1980; Imlay 1980).

5. Although some physical effects of commercial traffic can be simulated in the laboratory (Morgan et al. 1976; Holland 1986; Stevenson et al. 1986; Aldridge, Payne, and Miller 1987; Payne and Miller 1987; Killgore, Miller, and Conley 1987; Payne, Miller, and Aldridge 1987; and Way et al. 1989), caution must be exercised when using these results to predict impacts to naturally occurring organisms. Compensatory mechanisms exist in natural populations and responses noted in the laboratory usually do not occur in the field. Planners and biologists must evaluate the effects of man's activities on populations of species in their natural habitats. As an alternative to laboratory simulation, field studies should be conducted to evaluate the biological impacts of tow-induced disturbances.

6. Because it is endangered and uncommon, *L. higginsi* is not a good monitor of environmental change. When present, it usually comprises about 0.5 percent of a mussel community. Alternatively, biotic variables such as total mussel density, species richness, and evidence of recent recruitment can be readily measured and can be used to monitor the effects of habitat alteration or disturbance. These parameters provide the most useful measures of the

overall health and ultimate survival of a mussel community. With respect to studies on commercial navigation traffic, it may not be possible to identify true reference sites that are not affected by vessel passage. However, sites can be identified that differ in the intensity of physical disturbance caused by vessel passage. Experimental sites can be close to the navigation lane, and reference sites can be located as far from the physical effects of traffic as possible.

Study Design

7. Effects of incremental increases in commercial navigation traffic will be studied at mussel beds in the UMR. At each bed the following information on mussels will be obtained: total density, species richness and diversity, evidence of recent recruitment, population structure of dominant species, community composition, and individual physical condition of dominant species. In addition, changes in water velocity and suspended solids following passage of commercial vessels will be measured. Although this project is specifically designed to examine effects of commercial traffic, under certain conditions the physical effects of recreational craft will be included.

8. Physical and biological data will be collected at experimental and reference sites. Experimental sites will be located close to the navigation channel (affected by vessel passage), and reference sites will be as far as possible from the channel (to receive reduced or no effects of vessel passage).

9. Preliminary data for this project were obtained in July 1988. These data, to be discussed in this report, were used to identify mussel beds for detailed study. Physical and biological data will then be collected at these beds for 6 years, from 1989 to 1994. Each bed will be studied intensively every other year. Thus, 3 years of data (in addition to information obtained during the 1988 survey) will be obtained at each mussel bed. After 1994, biological and physical data will be collected at each bed once every 5 years. This will be done until traffic levels have increased by an average of one tow per day above 1990 levels in the pool where monitoring takes place. Studies will then resume at the original rate and continue until 2040, the economic life of the Melvin Price Locks and Dam Project. Results of these studies will be reviewed annually to determine the need for altering sampling protocol.

10. This design will enable three types of comparisons:

a. Comparisons within mussel beds. Physical data on the effects of vessel passage (changes in water velocity and suspended sediments), and ambient conditions for these parameters, will be obtained at nearshore and offshore sites at each mussel bed. These physical data can then be related to biotic conditions (density, species richness, etc.) within the mussel bed.

b. Comparisons among mussel beds. Data from nearshore and offshore sites can either be grouped or kept separate and then compared with similar information collected at the other mussel beds. The effects of different traffic intensities and physical conditions at these mussel beds in the UMR can be established.

c. Comparison between (or among) study years. Changes in physical and biological and physical variables through time will be measured at each mussel bed. These data will be correlated with changes in commercial navigation traffic to determine if commercial traffic is affecting physical or biological conditions at each mussel bed.

11. Data will be evaluated to determine if commercial navigation traffic is negatively affecting *L. higginsi*. This will be accomplished by collecting information on all bivalves at these mussel beds. A surrogate species concept is being used since it is extremely difficult to obtain information on density, recruitment, etc., for uncommon species such as *L. higginsi*. In addition, intensive collection of this species could be detrimental to its continued existence.

Description of Tasks

12. The following is a brief summary of tasks and subtasks for this study:

a. Task I: Monitor mussel communities. The purpose of this task is to identify and study beds in the UMR with dense and diverse assemblages of freshwater mussels. *Lampsilis higginsi* should be present (approximately 0.5 percent) at each bed identified for detailed study, with the exception of a bed in Pool 24 (RM 299.6) that was added in 1989. These mussel beds must be close enough to commercial navigation lanes so that the physical effects of vessel passage (increased water velocity and elevated suspended sediments) can be studied.

(1) Subtask IA: Selection of mussel beds. During 1988 and 1989, preliminary biological and physical data were obtained at candidate mussel beds in the UMR. The physical and biological data that were collected during these preliminary studies are listed in Table 1 and in Table A1 of

Appendix A. A total of three mussel beds were chosen in 1988 and an additional two beds will be identified in 1989.

(2) Subtask IB: Studies at mussel beds. At each mussel bed two sites will be identified: one close to the r vigation chaıııel and affected by physical effects of vessel passage (experimental site), the other removed from the channel and relatively unaffected by vessel passage (reference site). Quantitative and qualitative samples for mussels will be obtained at each site. Each mussel bed will be studied every other year for a minimum of 3 years. Studies will be initiated in 1989 and will end in 1994. At that time personnel from the USFWS, US Army Corps of Engineers, and other participating agencies will determine the extent and nature of additional studies. Consideration has been given to conducting studies at each mussel bed every fifth year until the year 2040.

b. Task II: Navigation impact studies. The purpose of this task is to obtain physical data on the effects of vessel passage at experimental and reference sites. Physical data to be measured include changes in the direction and magnitude of water velocity and changes in total suspended sediment concentration.

(1) Subtask IIA: Preliminary investigations. Preliminary studies on the physical effects of commercial vessel passage will be conducted in 1988 and 1989. Following completion of these preliminary investigations, detailed physical effects studies (Task IIB) will be initiated.

(2) Subtask IIB: Physical effects of navigation traffic. Physical data will be collected at two mussel beds during a low and moderately high water period each year. This work will be initiated in 1990 and will be continued for as long as deemed appropriate.

c. Task III: Manipulative experiments. The purpose of this task is to place populations of marked mussels at control and experimental sites at two of the mussel beds. Mussels will be retrieved by divers each year to obtain data on mortality and rate of growth. This task will begin in 1989.

d. Task IV: Mechanisms to reduce harm. The purpose of this task is to investigate prudent measures that can be initiated to protect *L. higginsi*. Recommendations on the feasibility of specific conservation measures for this species will be based on analysis of the literature and review of the results of the mussel studies in the UMR. This work will begin in 1991.

13. Results of this study will be reported via the following mechanisms:

a. Progress reports. By 1 February of each study year a short report will be prepared that describes methods, areas studied, major findings, and implication of the results.

b. Annual meeting. A meeting to discuss results and future plans will be held each study year.

c. Final reports. A final report, to include a complete synthesis of data and discussion of results, will be prepared at the completion of each task or major subtask.

Evidence of Negative Effects

14. Six parameters will be used to evaluate the effects of commercial navigation traffic on freshwater mussels and *L. higginsi*. These parameters will be based on data collected at each mussel bed. Results of the preliminary study (1988), and the 6 years (1989-1994) of detailed study will provide physical and biological information during existing conditions. Information obtained from studies in 1994-2040 will be compared with earlier results (1989-1994) to make an assessment of "negative effects." Personnel from the USFWS, LMS, and the US Army Engineer Waterways Experiment Station (WES) will meet each year to discuss findings. The following six parameters are considered to be indicative of the health of mussel beds and will be used to determine if commercial navigation traffic is negatively affecting freshwater mussels:

a. Decrease in density of five common-to-abundant species. Density of common-to-abundant species will be determined during studies conducted between 1989 and 1994. Negative effects will be assumed if there is a significant ($p < 0.1$) decline in density, sustained over each of at least two consecutive sampling periods (i.e., a study year), for at least five common-to-abundant species.

b. Absence of *L. higginsi*. During the preliminary survey (1988-89) and the detailed studies (1989-1994) the degree of effort required to obtain a specific number of *L. higginsi* will be determined. If *L. higginsi* are not collected on two consecutive sampling periods using this same effort, it will be assumed that this species is declining in abundance.

c. Decrease in live-to-recently-dead ratios for dominant species. Live-to-dead ratios for common-to-abundant species will be determined each study year. Negative effects will be assumed if there is a continual decrease in the live-to-recently-dead ratio for three consecutive sampling periods.

d. Loss of more than 25 percent of the mussel species. Total species richness will be determined at each bed during the preliminary and detailed studies. Negative effects will be assumed if subsequent sampling (sustained over two sampling periods) reveals a loss of more than 25 percent of the mussel species known to occur at the bed.

e. No evidence of recent recruitment. Evidence of recent recruitment will be determined for all species during the preliminary and detailed studies. If there are no signs of recruitment for two consecutive sampling periods for five common-to-abundant species, it will be assumed that the mussel bed has been negatively affected by traffic.

f. Significant reduction in growth rates or increase in mortality. Results of the exclosure experiments will be used to evaluate effects of commercial traffic on mortality and size-specific growth rates. If a significant reduction (0.05 level) at the affected site is identified, it will be assumed that the bed has been negatively affected by traffic.

PART III: STUDY AREA AND METHODS

Study Area

15. The UMR was once a free-flowing, braided, pool-riffle habitat with side channels, sloughs, and abandoned channels. Development of the 9-ft (2.74-m) navigation channel, which included placement of locks, dams, dikes, wing dams, and levees, converted it to a series of run-of-the-river reservoirs, characterized by relatively slow-moving water and extensive adjacent lentic habitats. Typically the upper reaches of pools in the UMR have relatively high water velocity and riverine conditions whereas the lower reaches are more lake-like with deep, low-velocity water and fine-grained sediments. Substrate in the lower portion of the UMR (Pools 26-24) consists mainly of coarse gravel, cobble, and slab rock. The channel is fairly narrow, deep, with comparatively few side channels, islands, or backwaters. The middle reach of the UMR (Pools 22-17) is characterized by fine-grained sediments, numerous islands, sloughs, and backwaters. The upper reach of the UMR (upriver of Pool 17) has extensive islands, backwaters, sloughs, and aquatic macrophytes. Substrate consist almost entirely of fine-grained sand and silt.

16. In July 1988, mussels were collected in Pools 26, 25, 24, 19, 18, 17, 14, and 11 (Table 1 and Appendix B). In addition, 32 qualitative samples were obtained at RM 708.5 (Pool 7) in 1987 and in 1988. At RM 708.5 the majority of the collections were from the right descending bank whereas in 1988 all samples were obtained along the left descending bank. Quantitative and qualitative samples have been obtained at Prairie du Chien in Pool 10 (near RM 635) since 1984 by personnel from WES. With respect to Prairie du Chien, this report deals only with qualitative samples collected in 1987, and with qualitative and quantitative samples collected in 1988. Quantitative samples were taken from the north portion of the east channel of the river that was dredged in 1976, and a reference site located about 0.5 km downriver. A summary of quantitative and qualitative samples obtained for this survey appears in Table 2.

Methods

Preliminary reconnaissance

17. Before intensive sampling was initiated, a diver made a preliminary survey of the study area. He obtained information on substrate type, water velocity, and presence of mussels. Collections were made only at beds with moderate to high densities of mussels (i.e., 10 or more individuals/m^2) that were at least 30 m wide and 0.5 km in length. A Fathometer was used to measure water depth, and distance to shore was determined with an optical range finder.

Qualitative collections

18. Qualitative collections were made by one or more divers equipped with SCUBA or surface air supply. Divers were instructed to search for and retain all live mussels until approximately 20 individuals were obtained. Usually at least 9 samples of about 20 individuals (held in nylon bags) were obtained at each site. Collecting was done mainly by feel since water visibility was poor. Mussels were brought to the boat and identified. Selected individuals were retained for voucher and analysis of shell morphometrics. Unneeded specimens were returned to the river. A summary of the information obtained during the preliminary reconnaissance of each mussel bed follows.

- a. Physical characteristics (i.e., sediment type, water depth, and velocity).
- b. Possible effects of commercial navigation traffic (i.e., distance from the sailing line).
- c. Size and location of the mussel bed.
- d. The number of mussel species and the difficulty of finding uncommon species.
- e. Presence of *L. higginsi*.
- f. Evidence of recent mussel recruitment.
- g. Spatial heterogeneity of the bed with respect to recent recruitment and species richness.
- h. Approximate number of quantitative samples required to estimate species richness and total density.

Quantitative sampling

19. A single diver removed all sand, gravel, shells, and live molluscs within a 0.25-m^2 quadrat. It usually took 5-10 min to clear the quadrat to a depth of 10-15 cm. All material was sent to the surface in a 20-ℓ bucket,

taken to shore, and sieved through a nested screen series and picked for live organisms. All bivalves were identified, weighed to the nearest 0.01 g on an electric top-loading balance, and total shell length was measured to the nearest 0.1 mm. All *L. higginsi* were returned to the river. Bivalves were measured alive in the evening and returned to the river the next day, or were preserved in 10-percent buffered Formalin and taken to WES for analysis.

20. Quantitative samples were obtained at seven locations in the UMR (Table 1). At two locations (RM 299.6 and 409.5) only 10 samples were obtained at a single site. At four locatons (RM 389.5, 433.3, 450.4, and 504.7) 10 samples were obtained at a nearshore site and 10 were obtained at a site farther offshore. Quantitative samples were usually taken at locations that exhibited high density and species richness based on preliminary and qualitative sampling. Sampling design at these latter four locations (i.e., inshore and offshore sites) was similar to the detailed sampling program to be initiated in 1989. Thirty quantitative samples were collected at each of two sites at RM 635. A set of quantitative samples was obtained in a barge turning zone that was dredged in 1976. A second set of samples was taken at a reference site located downriver.

21. Following is a list of biological and physical data that will be obtained at mussel beds chosen for detailed study (1989-1994). During the present preliminary (1988) studies, the majority of these data (except for items e, i, j, and k, were obtained at mussel beds where quantitative collections were obtained.

a. Species richness.

b. Relative abundance of each species.

c. Density of dominant species (adult and juveniles).

d. Size distribution of dominant species.

e. Live-to-recently-dead ratios for dominant species.

f. Evidence of recent recruitment.

g. Physical condition indices for dominant species.

h. Total wet biomass (for each individual and per square metre).

i. Substrate characteristics (grain size and organic content).

j. Physical conditions (water depth and velocity).

k. Water quality (dissolved oxygen, water temperature, total hardness and alkalinity, total and dissolved solids, etc.).

PART IV: RESULTS AND DISCUSSION

Community Composition

Qualitative sampling

22. A total of 15,146 bivalves, representing 34 species, were obtained in 667 qualitative samples in the UMR in 1987 and 1988 (Table 3). The fauna was dominated by *Amblema plicata*, which comprised 29.28 percent of all mussels collected, and was obtained in 87 percent of the samples. Fifteen species comprised from 1 to 8 percent of the bivalves, and 18 species comprised less than 1 percent of the fauna. Although they composed less than 10 percent of the assemblage, five species (*Obliquaria reflexa*, *Quadrula pustulosa*, *Obovaria olivaria*, *Truncilla truncata*, *Lampsilis ventricosa*, and *Leptodea fragilis*) were obtained in more than 50 percent of the samples.

23. Although *A. plicata* was dominant, it was not the most common bivalve at all locations (Appendix C, Table C1). This species comprised less than 5 percent of the assemblage at RM 347, RM 389, and RM 439, and at three beds it comprised less than 10 percent of the fauna. This species tended to become more common moving upriver, and was found in 100 percent of the samples obtained at RM 292, 442, 445, 499, 609, 612, and 635 (1987 only) (Table C2). Three species (*L. fragilis*, *Ellipsaria lineolata*, and *Quadrula quadrula*) exhibited the reverse trend and were more frequently collected in the lower reach of the UMR. *Megalonaias gigantea* was found in all of the samples at RM 232, although no other specific trends with respect to river mile were apparent. Seven species (*Q. quadrula*, *L. ventricosa*, *Q. pustulosa*, *Proptera* (=*Potamilus*) *alata*, *O. reflexa*, *O. olivaria*, and *T. truncata*) either showed no particular trends or tended to dominate in the middle reach of the UMR. *Lampsilis teres* and *Cumberlandia monodonta* were restricted to the lower and middle reach of the UMR, respectively. *L. higginsi* was found at only six locations; all of these were upriver of RM 442. A discussion of other sites where this species has been found appears in Appendix A.

24. The relationship between cumulative species (Y) and cumulative individuals (X) was compared for all qualitative samples obtained in 1988 (Figure 1). This relationship is expressed in Equation 1 below. The relatively high R^2 value indicates that all of the mussel beds studied, regardless

of location in the UMR, were similar with respect to the relationship between cumulative species and cumulative individuals.

$$Y = 8.3[illegible] \; \mathrm{Log}_e X - 2.06, \; N = 100, \; R^2 = 0.94 \qquad (1)$$

<u>Quantitative sampling</u>

25. Quantitative samples were obtained at each of six locations on the UMR; a total of 100 0.25-m^2 samples were obtained (Tables 1 and 2). Live mussels were found in all but two quadrats. The maximum number of individuals and species in a quadrat was 154 and 16, respectively (Figure 2). The relationship between total species (Y) and total individuals (X) is represented by the relationship:

$$Y = 6.54 \; \mathrm{Log}_e X - 0.88, \; N = 160, \; R^2 = 0.75 \qquad (2)$$

26. The comparatively low R^2 values result from combining samples with high and low density obtained at near- and offshore sites. Figure 2 includes basically two types of sites, those with few individuals (less than 10 or 15 individuals per 0.25-m^2 quadrat) and low species richness (less than five per 0.25-m^2 quadrat), and those with moderate to high numbers of individuals and high richness. Regardless, this relationship between species and individuals is significant at the 0.05 level.

27. Quantitative sampling, as compared with qualitative techniques, results in data with less individual size bias. For example, based on quantitative sampling, the fauna at RM 299.6 was dominated by *T. truncata* (34.6 percent), *O. reflexa* (17.9 percent) and *E. lineolata* (16.7 percent, Table D1). However, using qualitative techniques, the three dominant species at this location were *E. lineolata* (27.6 percent), *O. reflexa* (11.7 percent), and *A. plicata* (10.4 percent) (Table C2). Based on qualitative sampling, *T. truncata* comprised only 5.2 percent of the fauna at this bed. Unless total substrate collections are obtained, this smaller species is usually overlooked by divers.

28. Although determinations of community composition differ with respect to sampling method (see above), it should be apparent that rare species can usually be found equally well regardless of technique. When limitations of time and budget restrict the use of quantitative methods,

qualitative collections (i.e., incremental collections by divers) are very efficient for finding rare species. The relationship between cumulative species (Y) and cumulative individuals (X) for quantitative samples (Figure 3) is similar to the relationship expressed in Equation 1 and appears below (Equation 3). Regardless of sampling technique, the relationships between cumulative species and cumulative individuals at a mussel bed are similar.

$$Y = 9.14 \text{ Log}_e X - 2.59, \; N = 126, \; R^2 = 0.80 \qquad (3)$$

Consideration of Species Richness

29. In May 1987 qualitative samples of bivalves were obtained along the right descending bank in Pool 7, RM 708.5. A total of 2,087 individuals and 23 species (including two *L. higginsi*) were collected by divers during 20-min searches (Figure 4a). Cumulative species (Y) collected was related to the logarithm of cumulative individuals (X) by the relation:

$$Y = 13.76 \text{ Log}_e X - 22.13, \; N = 32, \; R^2 = 0.90 \qquad (4)$$

30. The inflection point after 10 species were collected was the result of moving into a series of very productive sites protected by wing dams. It is likely that all (or nearly all) of the species at this location were obtained by this intensive survey. The 23rd species was obtained after 1,432 individuals were collected; an additional 655 individuals yielded no new species.

31. In May 1988 the left descending bank of the river was surveyed using the same divers and methods. A total of 577 individuals and 13 species were obtained in 32 qualitative samples (Figure 4b). The relationship between cumulative species (Y) and cumulative individuals (X) was:

$$Y = 4.70 \text{ Log}_e X + 0.27, \; N = 32, \; R^2 = 0.95 \qquad (5)$$

32. Comparison of these two equations illustrates the differences in difficulty of finding rare species at two different locations in a mussel bed. Data from the right descending bank indicated that approximately 19 species could be obtained with a sample of 1,000 individuals. The regression equation

from the left descending bank indicated that approximately 14 species would be obtained with a sample of 1,000 individuals. Although the data appear to plateau for sites on the left descending bank with low species richness (Figure 4b), it is evident that more samples would be needed to ensure that additional species were not present. Based on Equation 2 above, 10,000 individuals would have to be collected along the left descending bank to obtain 23 species. There is no way of knowing if 23 species actually exist along the left descending bank, although the relationships above suggest that this is possible. It must be remembered that divers search a very small area for mussels that may be completely buried in the substrate and are not always distinguishable by touch.

Consideration of Species Diversity

33. Species diversity is a function of both species richness and evenness. Sampling locations that are dominated by a single species (as in the case of *A. plicata* in the upper reach of the UMR) usually have reduced diversity. However, as data from RM 708.5 illustrate, species diversity reaches a plateau rapidly as individuals are collected (Figure 5a). In addition, species diversity calculated after 20 species and 946 individuals (a total of 12 samples) had been collected was not substantially different from diversity calculated when all samples had been obtained (1.92 versus 1.90, Figure 5b). After the third sample, 131 individuals had been collected and 8 species had been identified. Species diversity was estimated at 1.57, which was only 0.35 less than the final value. Species richness, species diversity, and evenness values for the mussel beds surveyed using quantitative techniques appear in Table 4. Typically a greater number of species were found at nearshore sites, although species diversity tended to be slightly higher moving away from the shore. In addition, nearshore sites typically had lower evenness than offshore sites. This was probably the result of reduced dominance of one or two species at the offshore (as compared with nearshore) sites.

Density

34. Total density of mussels was significantly greater at nearshore sites as compared with offshore sites (Table 5 and Appendix D). Density for

all quantitative sites ranged from 5.2 individuals/m^2 at RM 409.5 to 333.2 individuals/m^2 at RM 450.4. Total live biomass was significantly greater at nearshore stations, and ranged from 102.3 g/m^2 at RM 409.5 to 7,791.4 g/m^2 at RM 635.0 for all sites sampled. Although higher densities were found at RM 409.5, the dominance of a relatively heavy individual (*A. plicata*) caused higher biomass values at RM 635 than the former site where *A. imbecillis* dominated.

35. The total number of 0.25-m^2 samples necessary to estimate total bivalve density at 0.95 confidence limits with either 10- or 20-percent error was estimated at all mussel beds where quantitative data were obtained (Table 6). Based on 10 samples from the 1988 survey, 26 to 345 samples would be required to provide total mussel density estimates with 10 percent of the actual mean. Between 4 and 86 samples would be required for estimates within 20 percent of the mean. Sites with very high variances (e.g., sites at RM 635) would not be good candidates for density comparisons because of the large possible sampling requirement. However, parameters other than density can be used to monitor changes in habitat characteristics.

Nearshore Versus Offshore Differences

36. With the exception of the mussel bed at RM 505, total mussel densities were significantly higher at nearshore than at offshore sites (Figure 6a). Offshore sites were usually located in water 5 to 10 ft (1.52 to 3.05 m) deeper than nearshore sites and these sites were typically exposed to higher current velocities (i.e., greater than 0.5 ft/sec (0.15 m/s)). However, no specific trend was apparent for juvenile mussels (defined here as those individuals less than 30 mm total shell length) with respect to distance from the shore at three of the mussel beds (Figure 6b). For example, at RM 433 and 505 the percentage of juveniles at the nearshore sites was slightly less than the percentages offshore, whereas at RM 450, juveniles were slightly more common at the nearshore than the offshore site. These data indicate that total mussel density (adults plus juveniles) was greater at nearshore sites, although juveniles did not dominate at either site. At RM 389 no juveniles were found at the offshore site. This latter site was in the navigation channel and was subjected to higher water velocities as well as possible periods of turbulence from passing tows.

37. Densities of selected species were often greater at sites close to the shore; for example, *A. plicata* and *A. imbecillis* were approximately twice as dense at nearshore sites versus those offshore (Figures 7a and 7b). However, there was no evidence that either of these species comprised a greater proportion of the nearshore assemblage; relative species abundance (Figures 7a and 7b) was about the same at both sites. Relative percentage abundance of individual species is dependent on community composition. For example, *A. plicata* comprised a substantially greater proportion of the community offshore than at the nearshore site (Figure 8a). The relatively greater proportion (albeit lower density) at the offshore site was the result of the lack of *A. imbecillis* in the deeper water (Figure 8b).

38. Differences in community composition between nearshore and offshore sites are depicted graphically in Figures 9 and 10. The nearshore assemblage at RM 389 was dominated by two species that comprised 81.3 percent of the fauna (Figure 9a). At the offshore site four species dominated and comprised 69.6 percent of the assemblage (Figure 9b). Nearshore and offshore fauna at RM 450 were similar; five species dominated and comprised 61.8 and 73.3 percent of the mussels at nearshore and offshore sites, respectively (Figures 10a and 10b). Differences between nearshore and offshore sites are dependent upon physical characteristics such as water velocity, depth, and substrate type. Percentage similarity (a relationship depicting the number of species common to two sites) varied from 24.7 to 86.0 (Table 7). Nearshore and offshore sites displayed the greatest community similarity at RM 450.4, although density differences between nearshore and offshore sites were most similar at RM 504.7.

Population Demography

39. Data from quantitative samples were used for preliminary analyses of population demographics. In all cases nearshore and offshore sites were grouped, although differences in density and relative species abundance were related to distance to shore. Sites were grouped to increase the number of individuals available for analysis and because significant intrasite differences were not evident. Data from subsequent sampling (when more individuals will be collected) will be used for more detailed analyses of intersite differences. Only species with suitably high numbers of individuals (i.e., at

least 25 or 30) were evaluated. Since bivalves are relatively long-lived and only a single set of samples was obtained, it was not always possible to identify individual cohorts or to determine rates of growth. Because bivalves grow more rapidly when they are small and young than when they are large and old, it is often possible to discern small but not large cohorts. Additional data (i.e., collection of more individuals over at least 3 years for most species) will be required to provide more detailed analyses of population structure. Furthermore, it should be recognized that 10 or more years of data would be required to follow growth through the life spans of most species.

Amblema plicata

40. Both populations (at RM 450.4 and RM 504.7, Figures E1 and E2, respectively) are characterized by a large number of cohorts that span a large size range. The latter site exhibited comparatively more small-sized individuals than the former. It should be noted that commercial shell collectors selectively harvest this species, which may have to be considered when analyzing future data sets. With more samples the apparent reduced numbers of individuals at 54-62 mm (RM 450.4) and at 75-84 mm (RM 504.7) could be better differentiated. Subsequent sampling at these sites could then be used to determine rate of growth of individual cohorts.

Anodonta imbecillis

41. This small-sized, thin-shelled species grows rapidly and has a relatively short life span. Size distributions at RM 389.5 and 450.4 (Figures E3 and E4, respectively) are virtually identical. It is likely that the abundant single cohort of mussels at 35-55 mm total shell length are approximately 14- to 16-month-old individuals, spawned in the late spring of 1987. Coker et al. (1921) report maximum growth of this species in the UMR to be 48 mm per year. Few if any individuals spawned in the late spring of 1988 would have been obtained in our samples because of their size. Since the distributions are essentially unimodal it is less likely that the organisms are 2 years old and that the 1987 cohort is missing or greatly reduced. One more year of sampling at both locations would provide useful information on the life history of this species. Because it has a short life span and is restricted to shallow water, *A. imbecillis* is an excellent study organism to evaluate effects of substrate composition and depth on density and population structure. Both of these physical factors will be important in this study of commercial navigation traffic effects.

Ellipsaria lineolata

42. Sufficient numbers of this species for demographic analysis were found only at RM 450.4 (Figure E5). The first observable cohort at 24 mm is composed of either 1- or 2-year-old individuals. More recent recruits (i.e., less than 10 mm) may have been present, although the current sampling techniques probably missed them. Results of future sampling will provide information on recruitment, growth, and longevity of the smallest cohort.

Leptodea fragilis

43. Size structure of populations at RM 389.5 and RM 450.4 (Figures E6 and E7, respectively) are similar. Both populations are characterized by comparatively few fairly recent recruits (60-90 mm total shell length) and large numbers of intermediate-sized individuals. This thin-shelled and relatively rapidly growing species appears to recruit regularly in the UMR. Popu lation structure of *L. fragilis* is similar to that of *A. imbecillis*.

Obliquaria reflexa

44. Sufficient individuals of this species for demographic analysis were found only at RM 504.7 (Figure E8). The majority of the specimens were between 21 and 48 mm total shell length, which probably represents at least two cohorts, although the histogram is not distinct and the sample size was small. Additional sampling will be required to obtain more complete information on the population structure of this species.

Potamilus alatus

45. Sufficient individuals of this species to plot size distribution were obtained only at RM 450.4 (Figure E9). This population is characterized by relatively few small-sized individuals (less than 50 mm total shell length), few large individuals (greater than 100 mm), and many intermediate-sized (60-90 mm) individuals. As with the previous species, additional sampling will be required to obtain more complete information on the population structure of *P. alatus*. However, since densities of this species are usually low, it is unlikely that enough specimens will be obtained to provide extensive information on its life history.

Quadrula pustulosa

46. Fairly large numbers of individuals of this species were collected at RM 433.3 and RM 450.4 (Figures E10 and E11, respectively). The population at the former location was characterized by large numbers of more recent recruits, although in other respects age structures were similar. At both

locations recruitment appears to occur regularly, and intermediate to large-sized organisms were common.

Quadrula quadrula

47. Moderate numbers of this species were collected at RM 433.3 (Figure E12). Age structure was similar to that of *Q. pustulosa*, although a large sample size will be needed to fully evaluate this population.

Truncilla donaciformis

48. This species grows to comparatively small adult size and its average life span may be about 1.5 years. The population at RM 450.4 (Figure E13) cannot be easily differentiated into cohorts. However, because of the short life cycle of this species a fall collection would probably yield two identifiable cohorts.

Truncilla truncata

49. Moderate to high numbers of *T. truncata* were collected at RM 299.6, 433.3, 450.4, and 504.7 (Figures E14-E17, respectively). The population at RM 299.6 appears to separate into 1-year-old (14-22 mm) and 2-year-old individuals (greater than 30 mm total shell length). The population at RM 433.3 may also consist of two cohorts although the majority of individuals at RM 450.4 and 504.7 (exclusive of the individual at 12 mm) probably contain a single cohort. Additional samples of this small-sized species (possibly at different times of the year) would be needed to follow changes in population structure.

Shell Morphometrics

50. Relationships between shell mass and shell length and between tissue dry mass and shell length were calculated for eight qualitative collections in the UMR (Appendix F). Values for R^2 were all 0.89 or greater. No specific trends in shell morphometrics with respect to river mile (pool) were noted. Specimens from Pool 19 (lower) had correspondingly greater dry mass of shell and viscera per shell length than did specimens from other pools. Conversely, *A. plicata* from Pool 26 had relatively reduced mass of dry shell and viscera per length of shell. Relationships for these parameters appear below:

	Shell Mass (Y) vs. Shell Length (X)		Tissue Mass (Y) vs. Shell Length (X)	
Pool	Equation	R2	Equation	R2
26	Y = 0.0098 X^ 2.14	0.89	Y = 0.0092 X^ 2.16	0.89
25	Y = 0.0014 X^ 2.56	0.98	Y = 0.0014 X^ 2.56	0.98
24	Y = 0.0075 X^ 2.23	0.89	Y = 0.0069 X^ 2.52	0.89
19 (U)*	Y = 0.0023 X^ 2.42	0.98	Y = 0.0022 X^ 2.44	0.99
19 (L)**	Y = 0.0008 X^ 2.64	0.99	Y = 0.0008 X^ 2.67	0.99
18	Y = 0.0038 X^ 2.30	0.99	Y = 0.0031 X^ 2.36	0.99
14	Y = 0.0025 X^ 2.41	0.91	Y = 0.0026 X^ 2.40	0.91
11	Y = 0.0031 X^ 2.37	0.94	Y = 0.0023 X^ 2.45	0.94

* U - Upper Pool
** L - Lower Pool

51. In addition to measures of shell length, shell mass, and viscera mass, total mass and organic content of shell and viscera have been determined. These data will be collected annually and at different seasons. This information will assist in characterizing intersite variations and will provide a mechanism for interpreting quantitative data in terms of mass as well as density.

PART V: SUMMARY

52. Mussels were collected using qualitative techniques at a series of mussel beds in the UMR in 1987-88. Mussel beds were located in Pools 26, 25, 24, 19, 18, 17, 14, 11, and 7, between RM 232 and 708. Qualitative sampling was used to provide a rapid assessment of density, diversity, and species richness. Logarithmic plots of cumulative species versus cumulative individuals were prepared that provided information on the ability of finding uncommon species. Although qualitative sampling can be biased toward large-sized individuals and species, information on relative species abundance was obtained.

53. At seven mussel beds in the UMR, located in Pools 24, 19, 18, 17, 14, and 10, either 10, 20, or 30 total substrate samples (0.25-m^2 quadrat) were collected. Quantitative samples were obtained at beds that were at least 1 km in length, and exhibited moderate to high density and species richness. At most of the beds, samples were collected at nearshore and offshore sites.

54. The following conclusions can be drawn from the 1988 preliminary studies on the UMR:

a. Species richness was a function of mussel density; the ability to find uncommon species is related to sampling effort and to numbers of individuals present.

b. Qualitative and quantitative techniques appear to be equally useful in obtaining uncommon species. However, determinations of relative species abundance can be biased by qualitative collections.

c. *A. plicata* dominated the majority of the samples, although at certain locations other species (*A. imbecillis*) were dominant.

d. For most of the locations surveyed, nearshore and offshore sites differed with respect to density and relative species abundance of selected species. Densities were usually higher at nearshore sites, although species richness appeared to be unaffected by depth. Certain species (notably *A. imbecillis*) are found nearshore, while other species (*O. olivaria*) are more common offshore. There was no evidence that juveniles comprised a greater percentage of the mussel assemblage at nearshore sites as compared with those offshore.

e. Distribution of certain species (*L. higginsi*, *L. teres*, and *C. monodonta*) were related to river mile. Distinctive trends with respect to river mile may be obscured by intrasite variability or simply may not exist.

f. It is premature to provide detailed demographic information as a result of 1 year of sampling. However, existing data are sufficient to identify species with multiple cohorts (*Q. quadrula*, *Q. pustulosa*, and *L. fragilis*) as well as populations with relatively rapid life cycles (*A. imbecillis*, *T. donaciformis*, and *T. truncata*).

g. Based on the results of these studies, it was determined that detailed studies should be conducted at mussel beds located at RM 504.7 (Pool 14) and RM 635 (Pool 10). These mussel beds exhibit high density and species richness and are large enough to identify at least two sites that will be differentially affected by the physical effects of vessel passage. None of these mussel beds will be negatively affected by dredging, outfalls, or proposed future developments. In addition, *L. higginsi* was present in sufficient quantities at these mussel beds (i.e., about 0.5 percent of the assemblage) to ensure collecting it in qualitative and quantitative sampling.

h As a result of meetings between the Corps and the USFWS, it was decided that monitoring studies would also be conducted at a mussel bed located at RM 299.6 (Pool 24). No *L. higginsi* have been found in this pool. However, this pool has higher traffic levels than the upper pools, and the sediment composition is sufficiently larger in size that the potential impacts from commercial navigation traffic on the mussel bed are worthy of investigation.

55. Sampling design and protocol used in this survey were appropriate for obtaining data on density, species richness, community composition, and population demographics to identify and evaluate the quality of mussel beds in the UMR. Future detailed studies (1989-1994) will be conducted at RM 504.7 and 635 to evaluate the effects of commercial navigation traffic on freshwater mussels and the endangered species *L. higginsi*. Based on results of the 1989 survey, three more beds will be identified for additional detailed studies.

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Table 1

Quantitative and Qualitative Mussel Collections in the UMR, July 1988

Qualitative Samples				Quantitative Samples				
River Mile	Distance to Shore, ft	Depth ft	No. of Samples	River Mile	Distance to Shore, ft	Depth ft	No. of Quads	Location*
				July 18, 1988, Pool 26				
232.2	25 R**	8	7	-	-	-	-	1
233.6	50 L†	12	6	-	-	-	-	2
234.2	50 L	7	14	-	-	-	-	3
239.6	110 L	13	17	-	-	-	-	4
				July 19, 1988, Pool 25				
247.5	30 L	5	8	-	-	-	-	5
259.1	120 L	10	18	-	-	-	-	6
259.1	25 L	5	3	-	-	-	-	7
259.1	250 L	15	3	-	-	-	-	8
259.2	100 L	11	6	-	-	-	-	9
259.2	140 L	12	6	-	-	-	-	10
259.2	25 L	5	6	-	-	-	-	11
				July 20, 1988, Pool 24				
292.2	120 R	10	9	-	-	-	-	12
299.6	220 R	14	9	299.6	135.0 R	15	10	13
299.6	280 R	16	9	-	-	-	-	14
				July 21, 1988, Pool 19				
389.0	1,000 L	14	8	-	-	-	-	15
389.5	250 R	15	9	-	-	-	-	16
389.5	450 R	5	9	389.5	450.0 R	15	10	17
389.5	650 R	15	9	389.5	650.0 R	15	10	18
389.6	170 R	18	9	-	-	-	-	19
				July 22, 1988, Pool 19				
407.1	130 L	14	9	409.0	280 R	7	10	20
407.5	190 L	14	9	-	-	-	-	21
407.5	100 L	14	9	-	-	-	-	22
407.8	145 L	16	9	-	-	-	-	23
409.5	280 R	7	9	-	-	-	-	24

(Continued)

* Location numbers refer to maps in Appendix B.
** R = right descending bank.
† L = left descending bank.

Table 1 (Continued)

Qualitative Samples				Quantitative Samples				
River Mile	Distance to Shore, ft	Depth ft	No. of Samples	River Mile	Distance to Shore, ft	Depth ft	No. of Quads	Location*
				July 23, 1988, Pool 18				
433.0	115 L	18	9	-	-	-	-	25
433.2	115 L	17	9	-	-	-	-	26
433.3	180 L	17	9	433.3	100 L	15	10	27
433.3	80 L	15	9	433.3	180 L	17	10	28
433.4	120 L	18	9	-	-	-	-	29
				July 24, 1988, Pool 17				
439.7	500 R	15	9	-	-	-	-	30
442.0	55 R	15	9	-	-	-	-	31
444.9	70 R	20	9	-	-	-	-	32
444.9	115 R	22	9	-	-	-	-	33
445.1	120 R	21	9	-	-	-	-	34
448.7	140 R	16	9	-	-	-	-	35
				July 25, 1988, Pool 17				
448.7	100 R	11	9	-	-	-	-	36
448.7	80 R	10	8	-	-	-	-	37
448.7	150 R	12	9	-	-	-	-	38
450.4	220 R	18	9	-	-	-	-	39
450.4	100 R	18	9	450.4	90 R	18	10	40
450.4	140 R	23	9	450.4	140 R	23	10	41
				July 26, 1988, Pool 14				
499.5	160 L	15	9	-	-	-	-	42
504.6	80 L	8	9	-	-	-	-	43
504.6	120 L	11	9	-	-	-	-	44
504.7	80 L	6	9	504.7	85 L	11	10	45
504.7	120 L	11	9	504.7	170 L	11	10	46
				July 27, 1988, Pool 11				
599.5	210 L	24	9	-	-	-	-	47
608.3	80 R	7	9	-	-	-	-	48
608.4	80 R	5	9	-	-	-	-	49
608.5	360 R	10	9	-	-	-	-	50
609.0	205 R	5	9	-	-	-	-	51
609.0	105 R	10	9	-	-	-	-	52
609.0	80 R	19	9	-	-	-	-	53
612.5	100 R	12	9	-	-	-	-	54

(Continued)

Table 1 (Concluded)

Qualitative Samples				Quantitative Samples				
River Mile	Distance to Shore, ft	Depth ft	No. of Samples	River Mile	Distance to Shore, ft	Depth ft	No. of Quads	Location*
				Sept 28, 1987, Pool 10				
635.0	50-500 L	12	81	-	-	-	-	55
				Sept 26, 1988, Pool 10				
635.0	50-250 L	12	43	-	-	-	30	56
				May 19, 1987, Pool 7				
708.5	100-500 R	14	32	-	-	-	-	57
				May 26, 1988, Pool 7				
708.5	100-500 L	12	32	-	-	-	-	58

Table 2

Qualitative and Quantitative Collection of Bivalves in the UMR

Location	No. Samples	No. Individuals
	Qualitative Collections (1987-88)	
Prairie du Chien (RM 635.0)		
1987	81	2,001
1988	43	699
Winter's Landing (RM 708.5)		
1987	32	2,087
1988	32	577
Pool 26-14 (RM 232.2-612.7)		
1988	479	9,782
Total	667	15,146

River Mile	No. Sites	No. Individuals
	Quantitative Collections (1988)	
299.6	1	78
389.5	2	512
409.0	1	13
433.3	2	436
450.4	2	1,176
504.7	2	253
635.0	2	845
Total	12	3,313

Note: For quantitative collections, ten 0.25 m^2-quadrat samples were taken at each river mile (mussel bed), with the exception of the bed at RM 635 where 30 quadrat samples were obtained.

Table 3

Data on Bivalves Collected in the UMR, 1987-1988*

	Total Individuals	Abundance (%)	Total Samples	Frequency (%)
Amblema plicata (Say 1817)	4,435	29.28	580	86.96
Obliquaria reflexa (Rafinesque 1820)	1,169	7.72	352	52.77
Quadrula pustulosa pustulosa (Lea 1831)	1,164	7.69	420	62.97
Obovaria olivaria (Rafinesque 1820)	1,159	7.65	345	51.72
Truncilla truncata (Lea 1860)	956	6.31	353	52.92
Lampsilis ventricosa (Barnes 1823)	950	6.27	357	53.52
Leptodea fragilis (Rafinesque 1820)	844	5.57	311	46.63
Anodonta imbecillis (Say 1829)	652	4.30	100	14.99
Potamilus alatus (Say 1817)	619	4.09	306	45.88
Quadrula quadrula (Rafinesque 1820)	563	3.72	316	47.38
Ellipsaria lineolata (Rafinesque 1820)	557	3.68	244	36.58
Fusconaia flava (Rafinesque 1820)	394	2.60	245	36.73
Megalonaias gigantea (Barnes 1823)	376	2.48	207	31.03
Quadrula metanevra (Rafinesque 1820)	200	1.32	132	19.79
Quadrula nodulata (Rafinesque 1820)	173	1.14	112	16.79
Ligumia recta (Lamarck 1819)	156	1.03	120	17.99
Truncilla donaciformis (Lea 1828)	144	0.95	78	11.69
Potamilus laevissima (Lea 1830)	115	0.76	63	9.45
Anodonta grandis grandis (Say 1829)	108	0.71	89	13.34
Actinonaias ligamentina (Lamarck 1819)	92	0.61	76	11.39
Arcidens confragosus (Say 1829)	85	0.56	75	11.24
Strophitus undulatus (Say 1817)	54	0.36	46	6.90
Lampsilis higginsi (Lea 1857)	45	0.30	42	6.30
Lampsilis teres (Rafinesque 1820)	36	0.24	21	3.15
Lasmigona complanata (Barnes 1823)	32	0.21	28	4.20
Elliptio dilatata (Rafinesque 1820)	25	0.17	24	3.60
Cumberlandia monodonta (Say 1829)	11	0.07	10	1.50
Corbicula fluminea (Muller 1774)	10	0.07	6	0.90
Lampsilis radiata siliquoidea (Barnes 1823)	5	0.03	4	0.60
Plethobasus cyphyus (Rafinesque 1820)	4	0.03	3	0.45
Pleurobema sintoxia (Rafinesque 1820)	5	0.03	4	0.60
Toxolasma parvus (Barnes 1823)	4	0.03	4	0.60
Fusconaia ebena (Lea 1831)	3	0.02	3	0.45
Anodonta suborbiculata (Say 1831)	1	0.01	1	0.15

Total bivalves: 15,146
Total species: 34
Total samples: 667

* Bivalves were collected using qualitative techniques.

Table 4

Data for Bivalves Obtained in Quantitative Collections from the UMR, 1988

River Mile	Location*	Total Species	Species Diversity**	Evenness	Mean No. Species/quadrat†
299.6	N/A	12	1.95	0.78	4.3
389.5	NS	20	1.47	0.49	8.6
389.5	OS	12	2.07	0.83	4.2
409.5	N/A	8	1.99	0.96	1.1
433.3	NS	20	1.94	0.65	8.0
433.3	OS	12	2.16	0.87	5.0
450.4	NS	21	2.17	0.71	12.2
450.4	OS	20	2.19	0.73	10.5
504.7	NS	17	2.32	0.82	6.6
504.7	OS	16	2.44	0.88	8.0
635.0	BTZ	14	1.80	0.68	2.8
635.0	BTZ	11	1.24	0.52	2.9
635.0	BTZ	14	1.25	0.47	4.0
635.0	RS	16	2.25	0.81	5.6
635.0	RS	18	1.80	0.61	6.8
635.0	RS	21	1.90	0.62	8.5

* Location N/A - single collection with no distinction between nearshore and offshore sites
NS - nearshore (usually less than 60 m from shore)
OS - offshore (usually greater than 60 m from shore)
BTZ - barge turning zone
R - reference site located about 1.0 km downriver

** Shannon-Weaver Diversity ($Log_{2.3026}$)

† 0.25 m^2

Table 5

Density and Biomass for Bivalves Obtained in the UMR, 1988*

River Mile	Location**	Distance to shore, ft	Density† No/sq m	SD	Biomass†† g/sq m	SD
299.6	NS	--	31.2de	13.4	1,179.3def	744.6
389.5	NS	450	181.2b	108.6	3,957.4b	2,402.6
389.5	OS	650	23.6de	12.7	3,067.6bcd	1,543.8
409.5	NS	--	5.2e	3.8	102.3f	165.5
433.3	NS	100	139.2bc	109.7	1,443.8cdef	1,134.0
433.3	OS	180	35.2de	18.3	4,161.8b	3,753.4
450.4	NS	90	333.2a	215.8	6,825.7a	3,315.5
450.4	OS	140	137.2bc	50.6	3,360.2bc	1,326.9
504.7	NS	85	44.0de	11.2	2,352.8bcde	1,102.8
504.7	OS	170	57.2de	17.2	2,511.5bcde	1,101.7
635.0	BTZ	--	21.2de	19.7	822.4ef	935.3
635.0	BTZ	--	32.4de	18.9	1,485.9cdef	1,398.3
635.0	BTZ	--	46.0de	20.2	1,834.5cdef	1,551.8
635.0	RS	--	74.4cde	26.7	7,071.1a	2,114.6
635.0	RS	--	71.6cde	20.4	7,206.2a	2,425.2
635.0	RS	--	92.4cd	18.3	7,791.4a	2,539.4

* Mean values followed by the same letter are not significantly different, Duncan's Multiple Range Test (P = 0.05).

** Location:
- NS - Nearshore
- OS - Offshore
- BTZ - Barge turning zone
- RS - Reference site

† F = 14.24, P = 0.0001

†† F = 16.39, P = 0.0001

Table 6

Samples Required to Estimate Total Bivalve Density at a 0.95 Confidence Limit*

River Mile	Location**	N	No. Samples Required (Percent Error) 10	20
299.6	NS	10	74	18
389.5	NS	10	144	36
389.5	OS	10	116	29
409.5	NS	10	214	53
433.3	NS	10	248	62
433.3	OS	10	108	27
450.4	NS	10	168	42
450.4	OS	10	54	14
504.7	NS	10	26	6
504.7	OS	10	36	9
635.0	BTB	10	345	86
635.0	BTB	10	136	34
635.0	BTB	10	77	19
635.0	RF	10	51	13
635.0	RF	10	32	8
635.0	RF	10	16	4
635.0	BTB	30	168	42
635.0	RF	30	34	9

* Data based on 10 or 30 quantitative samples

** Location: NS - Nearshore
OS - Offshore
BTB - Barge turning basin
RF - Reference site

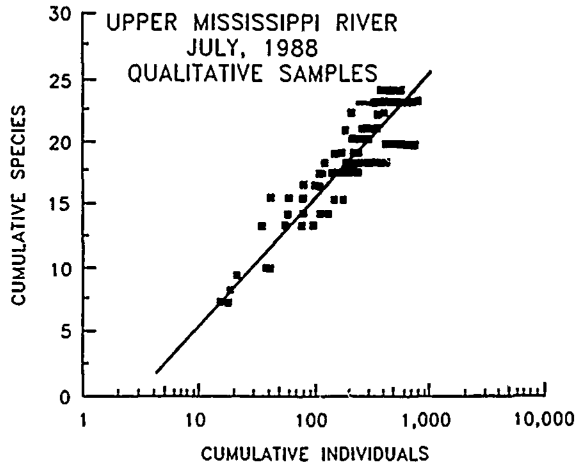
Table 7

Community Comparisons for Mussel Assemblages at Four Locations in the UMR, July 1988*

River Mile	Location	Total Species	Common Species	Percent Similarity	Morisita's Index
389.5	Nearshore	20	11	24.7	0.08
	Offshore	12			
433.3	Nearshore	20	12	70.0	0.78
	Offshore	11			
450.4	Nearshore	21	19	86.0	0.99
	Offshore	20			
504.7	Nearshore	17	13	67.9	0.84
	Offshore	16			

* Ten 0.25-m^2 quadrats were collected at each site.

Figure 1. Relationship between cumulative species (Y) and cumulative individuals (X) for all qualitative samples obtained in 1988



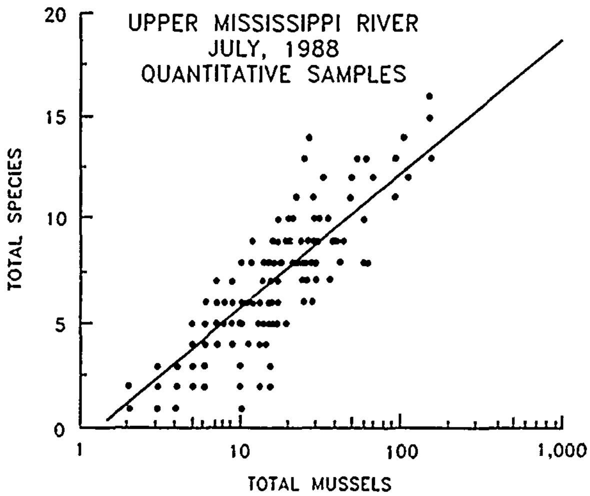
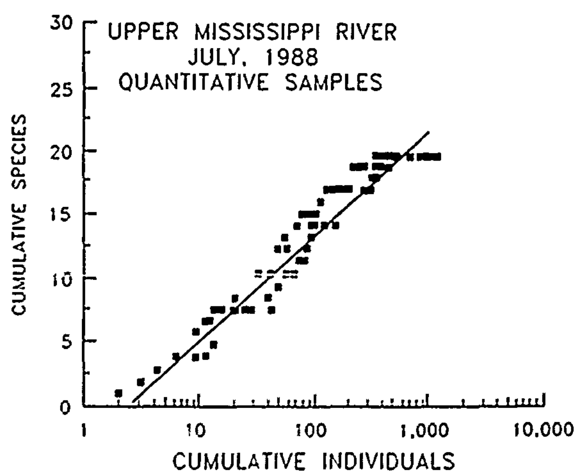
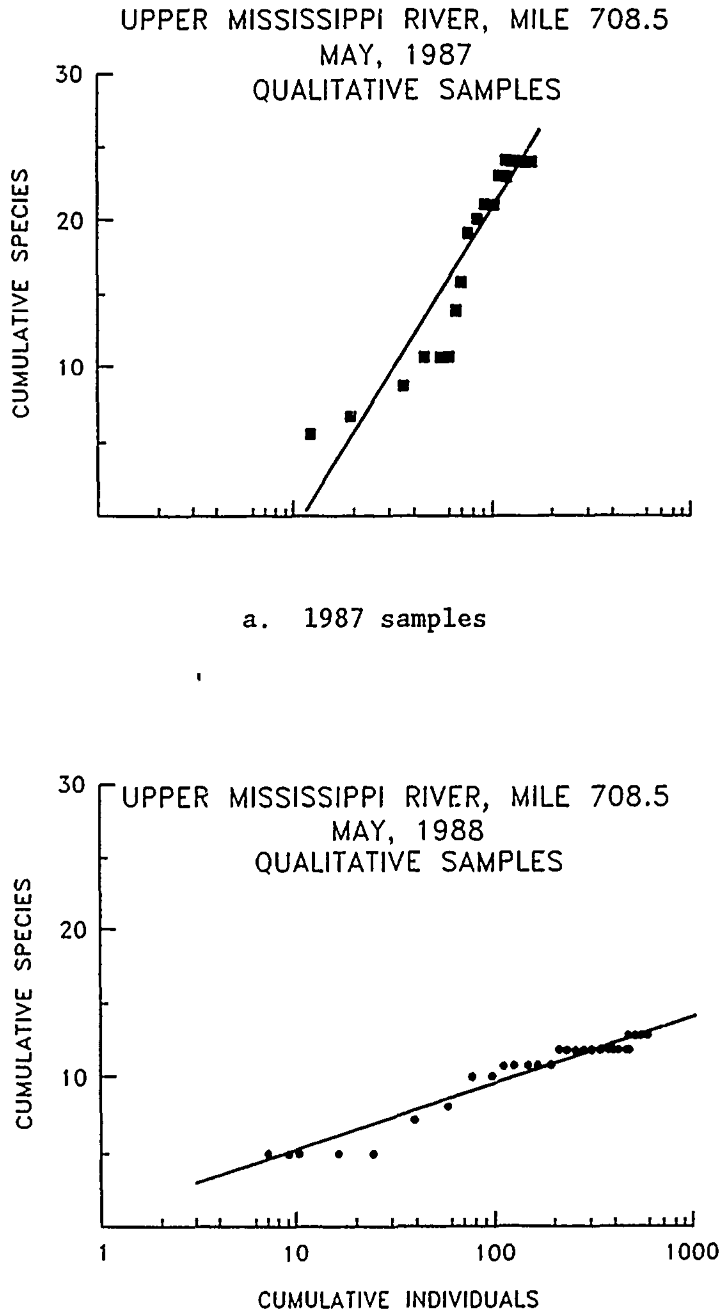


Figure 2. Relationship between total species (Y) and total individuals (X) for quantitative samples obtained in 1988

Figure 3. Relationship between cumulative species (Y) and cumulative individuals (X) for quantitative samples obtained in 1988

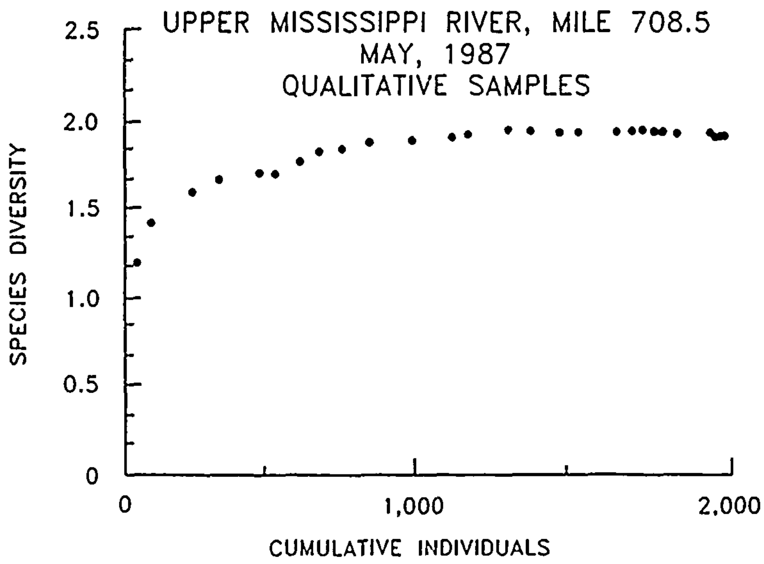




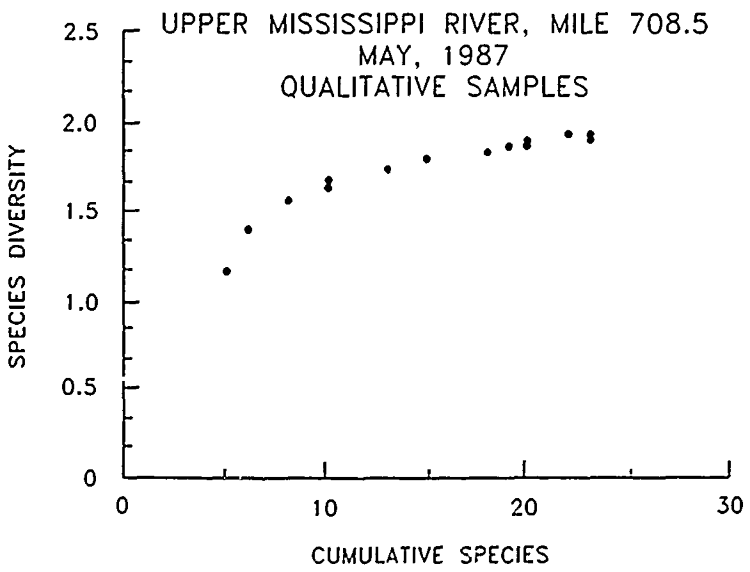
a. 1987 samples

b. 1988 samples

Figure 4. Relationship between cumulative species (Y) and cumulative individuals (X) for qualitative samples

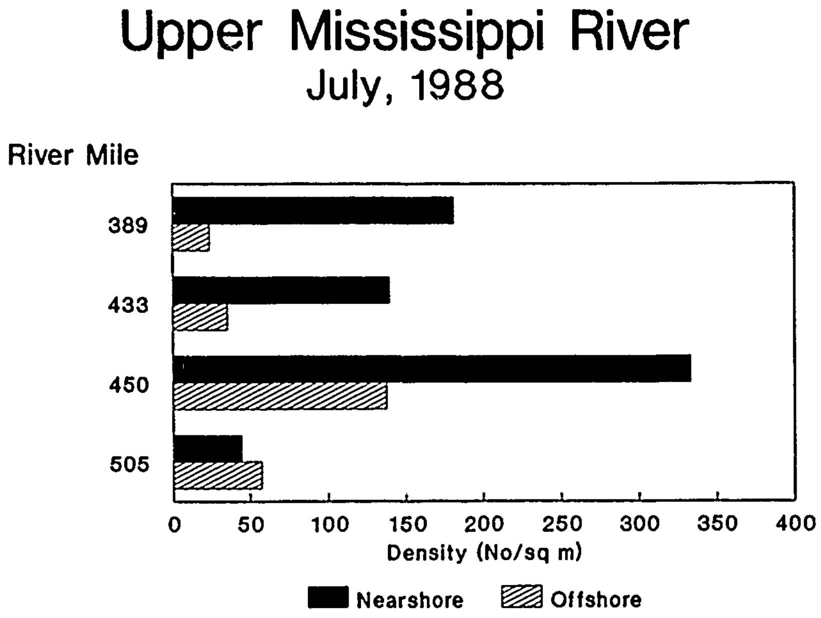


a. Relationship between species diversity and cumulative individuals

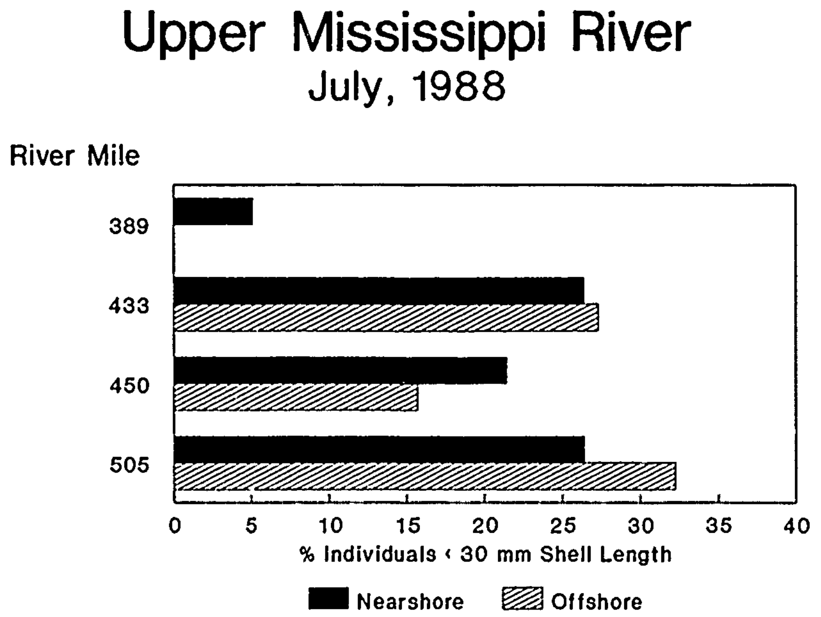


b. Relationship between species diversity and cumulative species

Figure 5. Species diversity for qualitative samples obtained in 1987

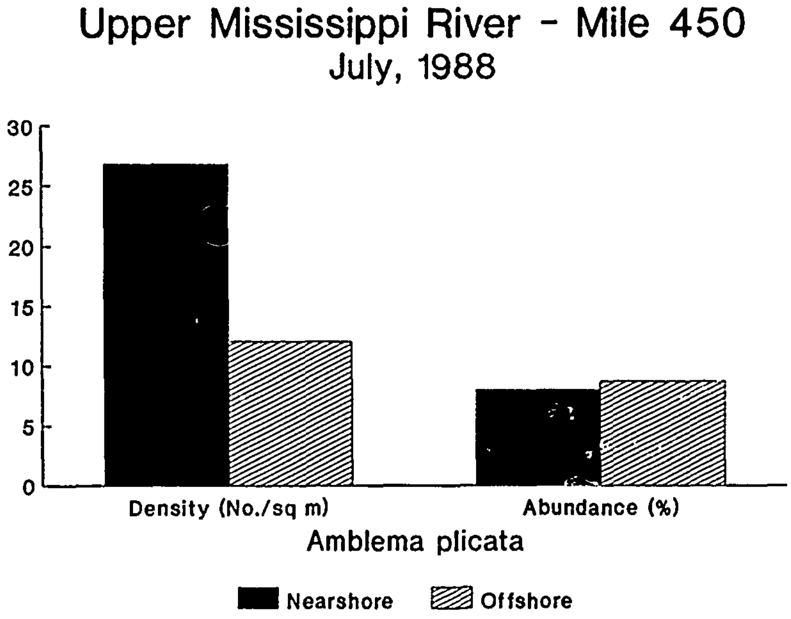


a. Mussel density at nearshore versus offshore sites

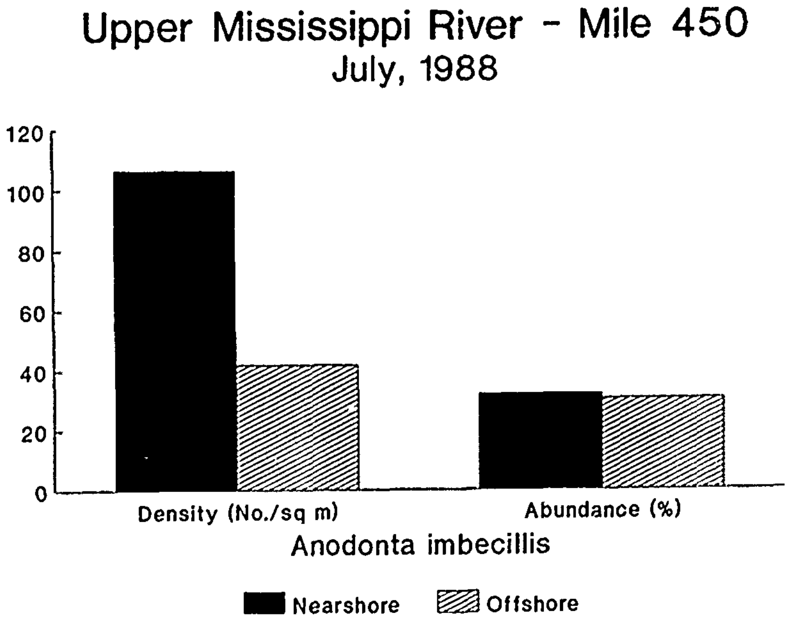


b. Percentage of juvenile mussels at nearshore versus offshore sites

Figure 6. Nearshore versus offshore differences

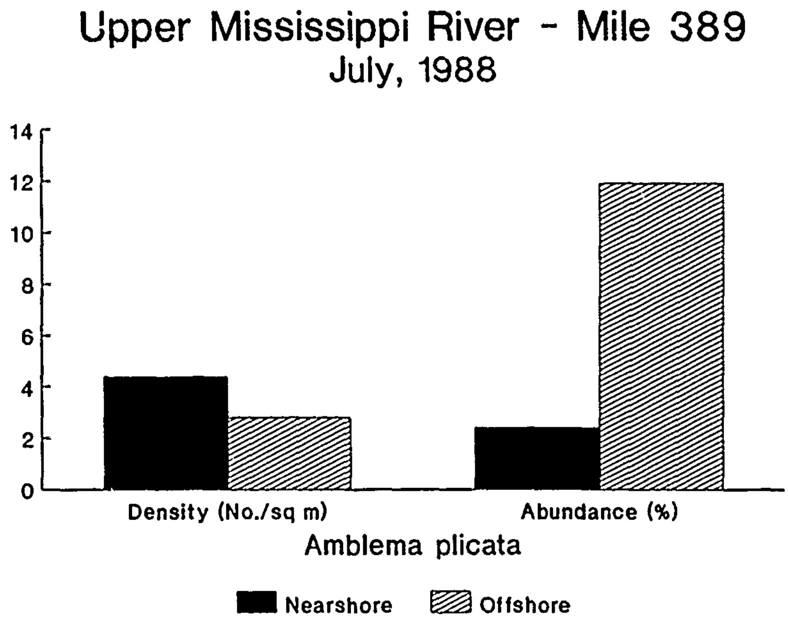


a. *A. plicata*

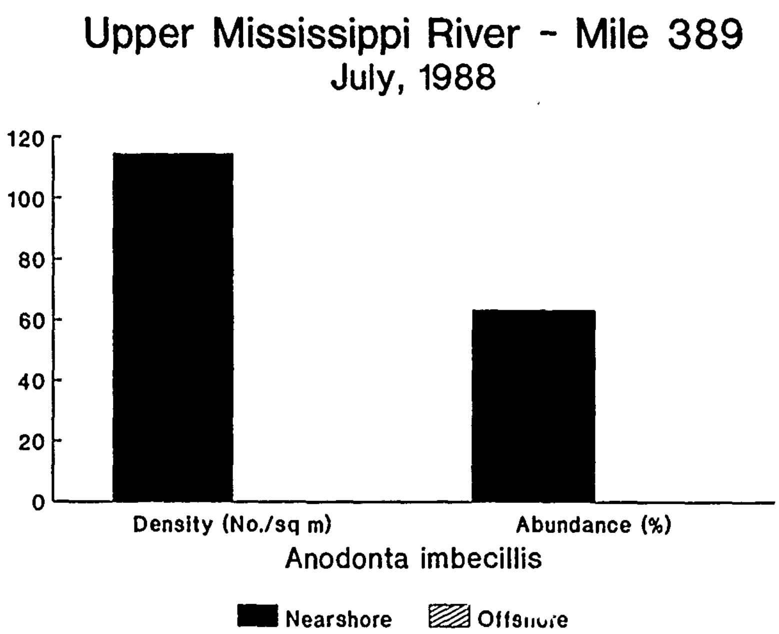


b. *A. imbecillis*

Figure 7. Density of individual species at nearshore versus offshore sites, RM 450



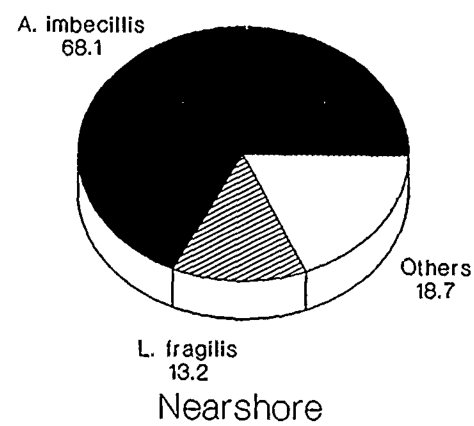
a. *A. plicata*



b. *A. imbecillis*

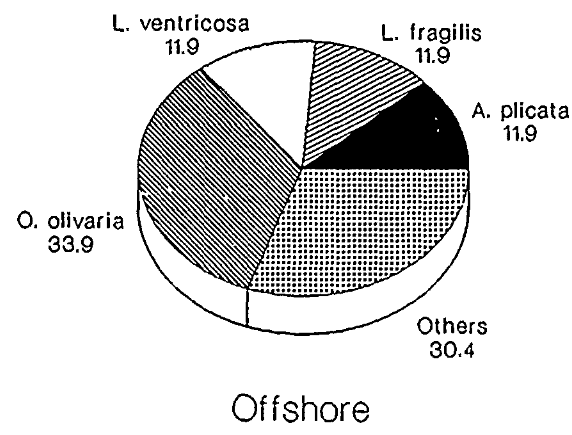
Figure 8. Density of individual species at nearshore versus offshore sites, RM 389

Upper Mississippi River - Mile 389
July, 1988



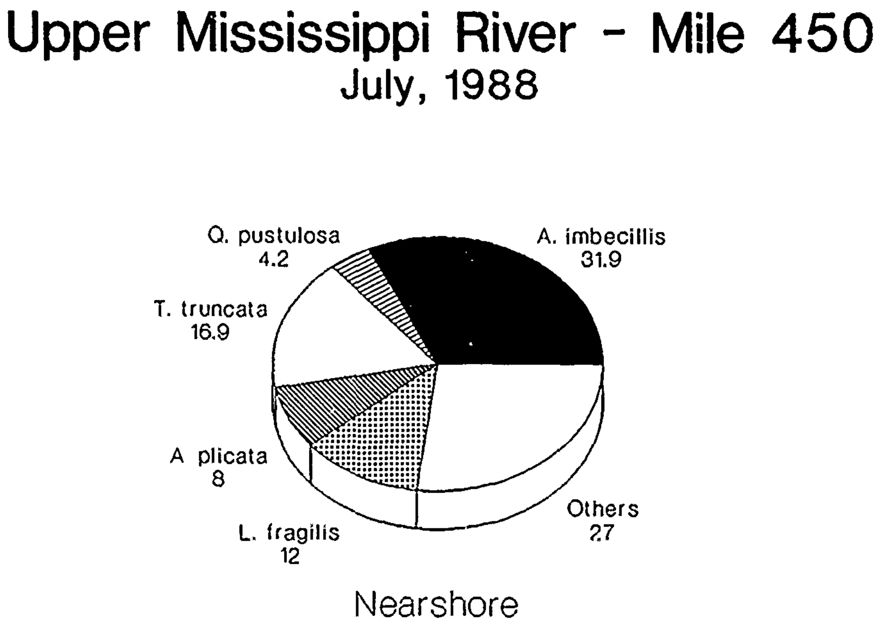
a. Nearshore site

Upper Mississippi River - Mile 389
July, 1988

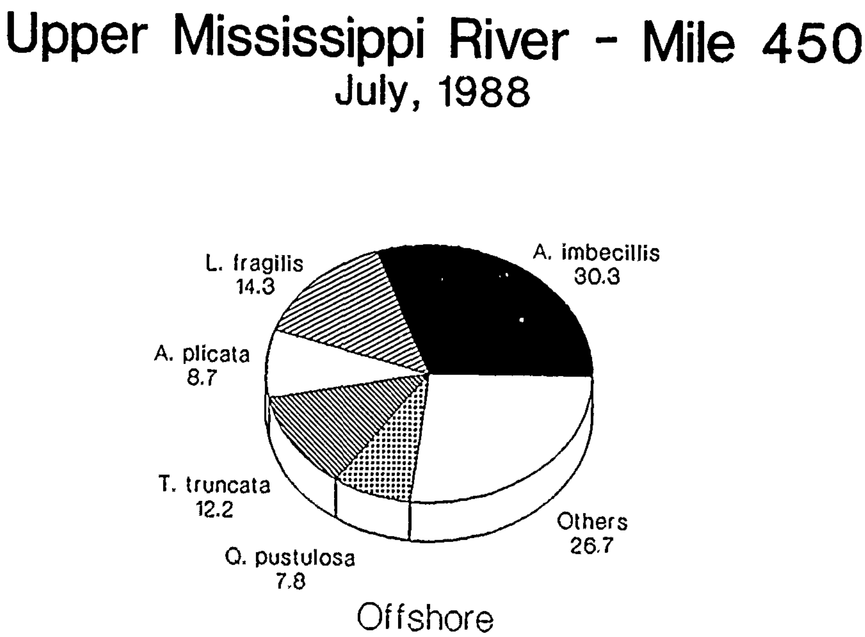


b. Offshore site

Figure 9. Community composition at RM 389



a. Nearshore site



b. Offshore site

Figure 10. Community composition at RM 450

APPENDIX A

SELECTION OF MUSSEL BEDS FOR DETAILED STUDY

Background

1. The purpose of Task Ia was to identify at least four mussel beds for detailed study. During 1988 candidate beds were visited to obtain preliminary biological and physical data for the selection process. Biological data from the most promising mussel beds were assembled (Table A1). Physical data for these beds were obtained from the US Army Engineer Districts in St. Louis, St. Paul, and Rock Island (Table A2). This information was used to identify mussel beds for detailed study.

Mussel Beds Considered for Detailed Study

2. Dr. Ed Cawley (Loras College, Iowa) has conducted numerous studies on mussels of the Upper Mississippi River (UMR). The following is an analysis of the mussel beds that he studied and their potential for detailed study as part of this program.

RM 445

3. Cawley (1984)* collected mussels at Kilpeck Island (RM 445, Pool 17) in the summer of 1984. He reported that *Lampsilis higginsi* comprised 0.36 percent of the assemblage. In the present survey, 561 mussels were collected in 27 qualitative samples at three sites near Kilpeck Island (see the map on page B11). Although *L. higginsi* was not obtained, 24 species were identified. Since Cawley (1984) reported that 0.36 percent of the assemblage consisted of *L. higginsi*, it is assumed that at least two individuals of this species should have been obtained at this location during the present survey. Additional collections will be made in this river reach in 1989 as part of the process of locating mussel beds for detailed study.

RM 409.5

4. Cawley (1984) reported that *L. higginsi* comprised 0.32 to 0.50 percent of the mussel assemblage at Hog Island downriver of Lock and Dam 18. In the present survey, 175 mussels and 14 species but no *L. higginsi* were obtained in nine qualitative samples. Based on the relative species abundance of *L. higginsi* at this location (Cawley 1984), at least one specimen of this species should have been found during this reconnaissance. However, this bed

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* See References at the end of the main text.

would not be suitable for detailed study because it is located immediately below Lock and Dam 18. Flow and current patterns will be affected to an unknown extent by releases from the dam.

RM 407

5. Cawley sampled at Drew Chute, RM 407, in Pool 19 of the UMR. *L. higginsi* comprised 0.2 percent of the assemblage. In the 1988 reconnaissance, 703 mussels were obtained in 36 qualitative samples at four sites that corresponded to those of Cawley (1984). Twenty-three species were obtained, although no *L. higginsi* were collected. Based on the percentage reported by Cawley (1984), at least one *L. higginsi* should have been obtained. This site is close to the navigation channel and would be suitable for further study. Additional reconnaissance at this location will be conducted in 1989.

RM 449

6. Cawley (1984) reported that *L. higginsi* comprised 0.32 percent of the assemblage at Port Louisa, RM 449 in Pool 17 of the UMR. In the present survey 203 mussels, including 1 live specimen *L. higginsi*, were collected at this location. However this reach will not be suitable for navigation studies; the bank is steep and mussels are uncommon. Twenty 0.25-m^2 samples were obtained at RM 450.4, but no *L. higginsi* were collected. Since this species appears to be in the immediate area, more collections will be made in this river reach in 1989.

RM 406

7. Cawley (1984) sampled at O'Connell Slough, RM 406, and reported that *L. higginsi* comprised 0.55 percent of the assemblage. This mussel bed was not studied in 1988 because it is located in a slough and is removed from commercial navigation traffic.

RM 581.5

8. Cawley (1978) collected one *L. higginsi* at RM 581.5 in Pool 12. This mussel bed will be investigated in 1989.

Consideration of *L. higginsi*

9. Using qualitative techniques, *L. higginsi* was found at six locations in the UMR. The river miles and total number collected appear below:

River Mile	Pool	No.	% of Collection
442	17	1	0.49
450	17	1	0.18
504	14	8	1.09
609	11	8	0.66
635*	10	13	0.65
635	10	12	1.72
708	7	2	0.10

* Sampled in 1987. All other locations were surveyed in 1988.

10. Mussel beds at RM 442, 450, and 708 had low densities and comparatively few numbers of *L. higginsi*. However at RM 609, eight *L. higginsi* were obtained and 25 species were collected. However, quantitative samples were not obtained because of the large number of commercial shellers in this river reach. The bed at RM 504 exhibited high species richness, moderate to high densities, and had comparatively high numbers of *L. higginsi*. The site at RM 635 had high species richness, high densities, and comparatively high numbers of *L. higginsi*. Although a single *L. higginsi* was found in qualitative samples at RM 450.4, none were obtained in quantitative samples (Table D5).

11. *L. higginsi* was found at only two of the seven mussel beds studied quantitatively in 1988, at RM 504 and RM 635. At the former location *L. higginsi* comprised 0.91 percent of the nearshore assemblage, but was not found offshore. At RM 635.0 (near Prairie du Chien, WI) this species comprised 0.40 and 0.17 percent of the collection at a barge turning zone and a reference site, respectively. In addition, a diverse fauna was found at both sites.

12. Based upon an evaluation of all relevant physical and biological data, three mussel beds were chosen for detailed study beginning in 1989. One bed will be at RM 505 (Pool 14), and one bed will be at RM 635 (Pool 10). These beds were chosen because they exhibited high species richness, high density, and *L. higginsi* was common enough to be collected using quantitative and qualitative techniques. In addition, these beds were close enough to the navigation channel so that control and experimental sites could be identified. Neither of these mussel beds will be affected by outfalls, dredging, or other man-made disturbances (Table A1). In addition to biological monitoring, water velocity data will be collected at RM 505 and 635 during the summer and fall of 1989. Reconnaissance will be conducted in 1989 to choose additional mussel beds for study in 1990.

13. In addition, it was decided that monitoring studies would be initiated in 1989 in the upper portion of Pool 24, RM 299.6. Studies in this pool will be conducted every other year, as with the other sites. *L. higginsi* has not been found in this pool. However, personnel from the US Fish and Wildlife Service requested detailed studies at this site since it was at the lower reach of the UMR and could potentially be affected by higher traffic levels than the upper pools. In addition, the substrate in this pool consisted of high percentages of cobble and rock, and it was therefore quite different from pools in the upper river where silt and sand predominated.

Table A1

Important Physical Characteristics at River Reaches in the Upper Mississippi River Considered for Detailed Mussel Studies*

Considered for Study		Major Cities		Outfalls		Dredging		Planned Developments			Commercial Navigation Traffic**		
Pool	RM	Location	RM	Type	RM	Schedule	RM	Type	RM	Year	1986	1987	1988
24	299.6	Saverton, MO	302.5	--	--	--	--	--	--	--	2726/294	3250/328	3500/358
19	389	Dallas City, IL	390	--	--	None	390.2-391.0	--	--	--	2094/236	2463/282	3[illegible]85/320
18	433	New Boston, IL	433	--	--	10	432.9-434.4	--	--	--	2051/238	2450/280	3054/319
17	442	--	--	--	--	None	438.7	Big Timber	443.0-445.0	P	2178/250	2524/295	311[illegible]/330
17	450	--	--	--	--	None	451.5-451.8	--	--	--	"		"
14	505	Cordova, IL	503	--	--	--	--	--	--	--	1720/205	2179/270	2619/275
14	505	Princeton, IO	502	--	--	4	503.0-504.0	Wing Dams	503.0-504.2(LDB) 505.7-506.2(RDB)	P P	"	"	"
13	540	--	--	--	--	5	539.0	--	--	--	1474/168	1837/231	2209/227
12	557	Bellevue, IO	556	--	--	--	--	Brown's Lake	544.0-546.0	C	1400/165	1597/202	1945/210
12	581	Dubuque, IO	582	--	--	None	581.5	Islands	556.0-592.0	C	"	"	"
11	609	Cassville, IO	607	--	--	10	608.0-610.0	Berton McCartney	599.0-602.5	P	649/77	692/86	896/101
10	635	Prairie du Chien, WI	635	Domestic	633.8	N/A	--	--	--	--	N/A	N/A	N/A
10	635	Prairie du Chien, WI	635	Domestic Domestic Condenser cooling Unknown	646.0 646.0 663.0 637.7	N/A	--	--	--	--	1484/330	1433/164	1564/183
7	708	Winter's Landing, IO	708	--	--	N/A	--	Wing Dams	708	1989-90	1424/308	1302/135	1440/176

* To be considered, all outfalls, areas to be dredged, and developments must be within two river miles (upriver) of the area under consideration.

** Commercial navigation traffic
   Number of tows per year/number of tows in September of that year
   N/A - Not available

Dredging Schedule
   The number refers to dredging cycle (i.e., once every 4, 5, or 10 years)
   N/A - Not available

Year
   C - Now under construction
   P - Planned for construction

Table A2

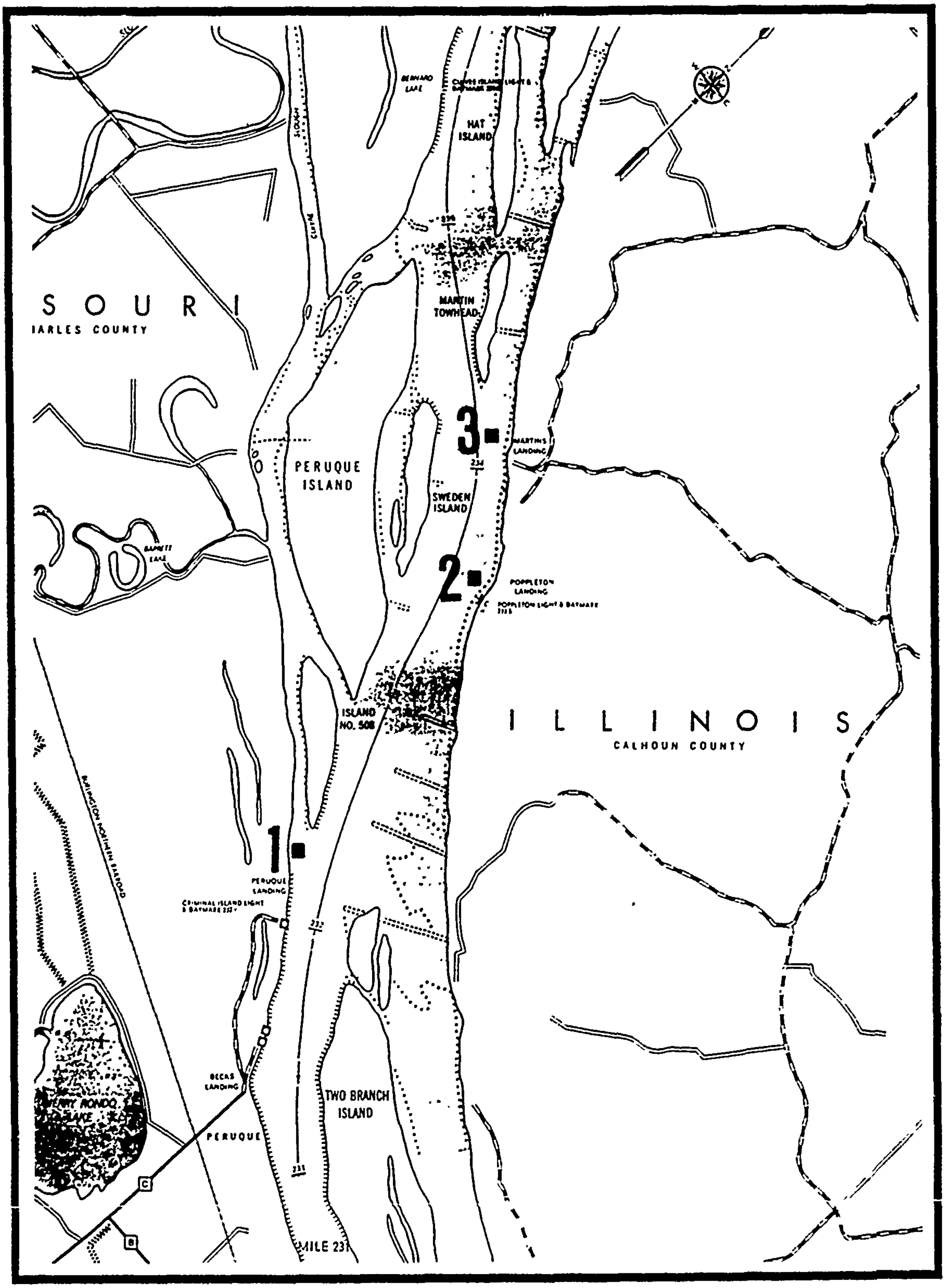
Important Biotic Characteristics of Mussel Beds Surveyed in the Upper Mississippi River Using Qualitative and Quantitative* Techniques (Sampling Conducted in 1988 Unless Noted Otherwise)

		Qualitative				Quantitative				
Pool	RM	Total Mussels	Total Species	*L. higginsi* No.	*L. higginsi* %	Total Mussels	Mussels % < 30 mm	Density No./sq m	*L. higginsi* No.	*L. higginsi* %
24	299.6	326	16	0	(0.00)	78	34.6	31.2	0	(0.00)
19	389	1,036	23	0	(0.00)	453	5.1	181.2	0	(0.00)
18	433	975	23	0	(0.00)	348	26.4	139.2	0	(0.00)
17	442	203	22	1	(0.49)	--	--	--	-	--
17	450	567	24	1	(0.18)	833	21.4	333.3	0	(0.00)
14	505	734	20	8	(1.09)	110	26.4	44.0	1	(0.91)
11	609	1,217	25	8	(0.66)	--	--	--	-	--
10	635**	2,001	12	13	(0.65)	514	34.4	68.5	4	(0.78)
10	635†	699	21	12	(1.72)	596	24.5	79.5	1	(0.17)
7	708††	2,087	23	2	(0.10)	--	--	--	-	--
7	708‡	577	13	0	(0.00)	--	--	--	-	--

* All samples were collected from nearshore sites. Ten samples were collected from all sites except RM 635 where 30 samples were collected.
** The majority of the samples were obtained in the East Channel in 1987.
† All samples were obtained in the Main Channel in 1988.
†† The majority of the samples were obtained on the right descending bank in 1987.
‡ The majority of the samples were obtained on the left descending bank in 1988.

APPENDIX B

SITES IN THE UPPER MISSISSIPPI RIVER SURVEYED FOR BIVALVES, 1987-88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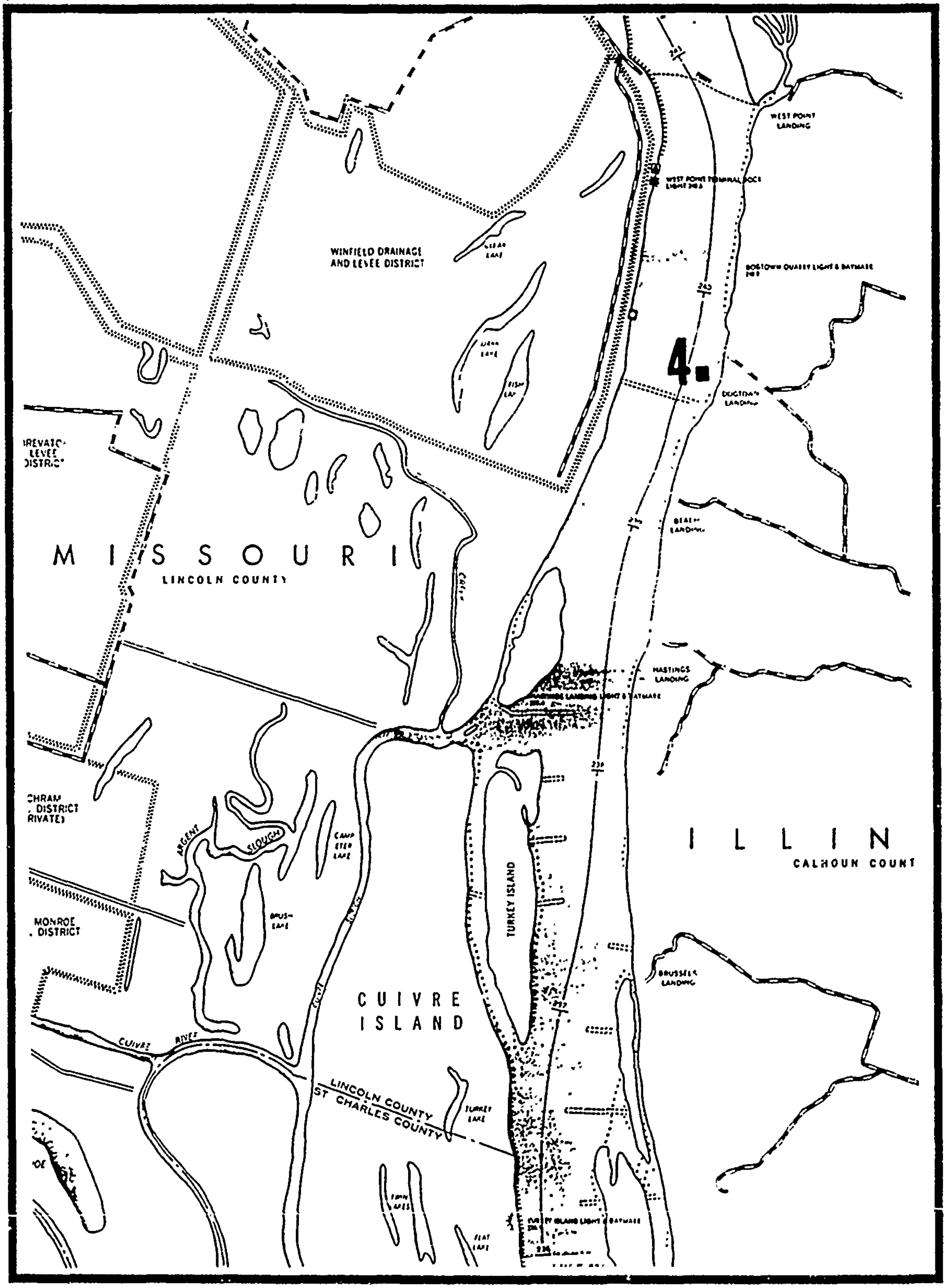
IARLES COUNTY
HAT ISLAND
MARTIN TOWHEAD
PERUQUE ISLAND
SWEDEN ISLAND
3
MARTINS LANDING
2
POPPLETON LANDING
ISLAND NO. 508
ILLINOIS
CALHOUN COUNTY
1
PERUQUE LANDING
TWO BRANCH ISLAND
PERUQUE
MILE 231
C
B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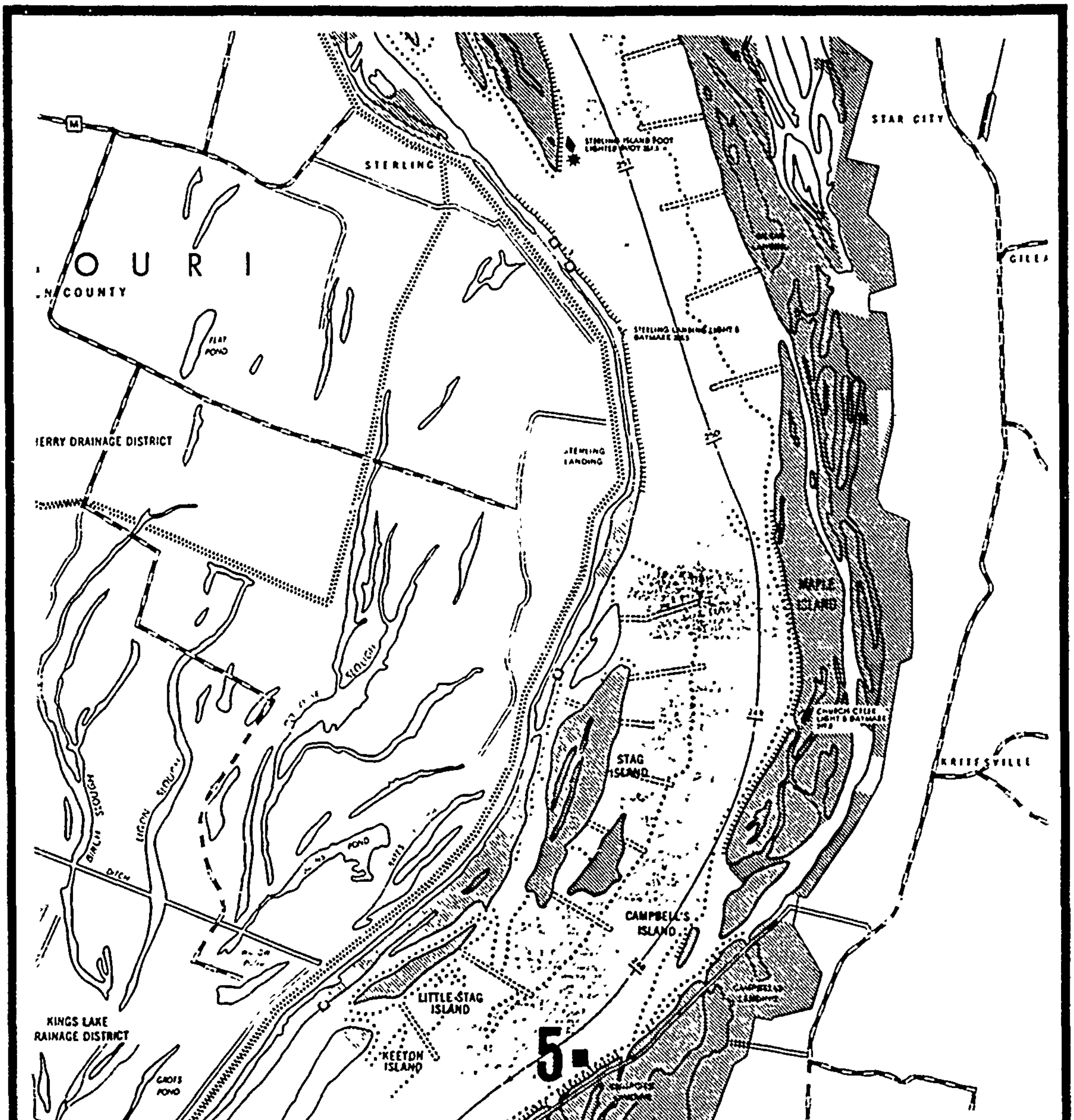
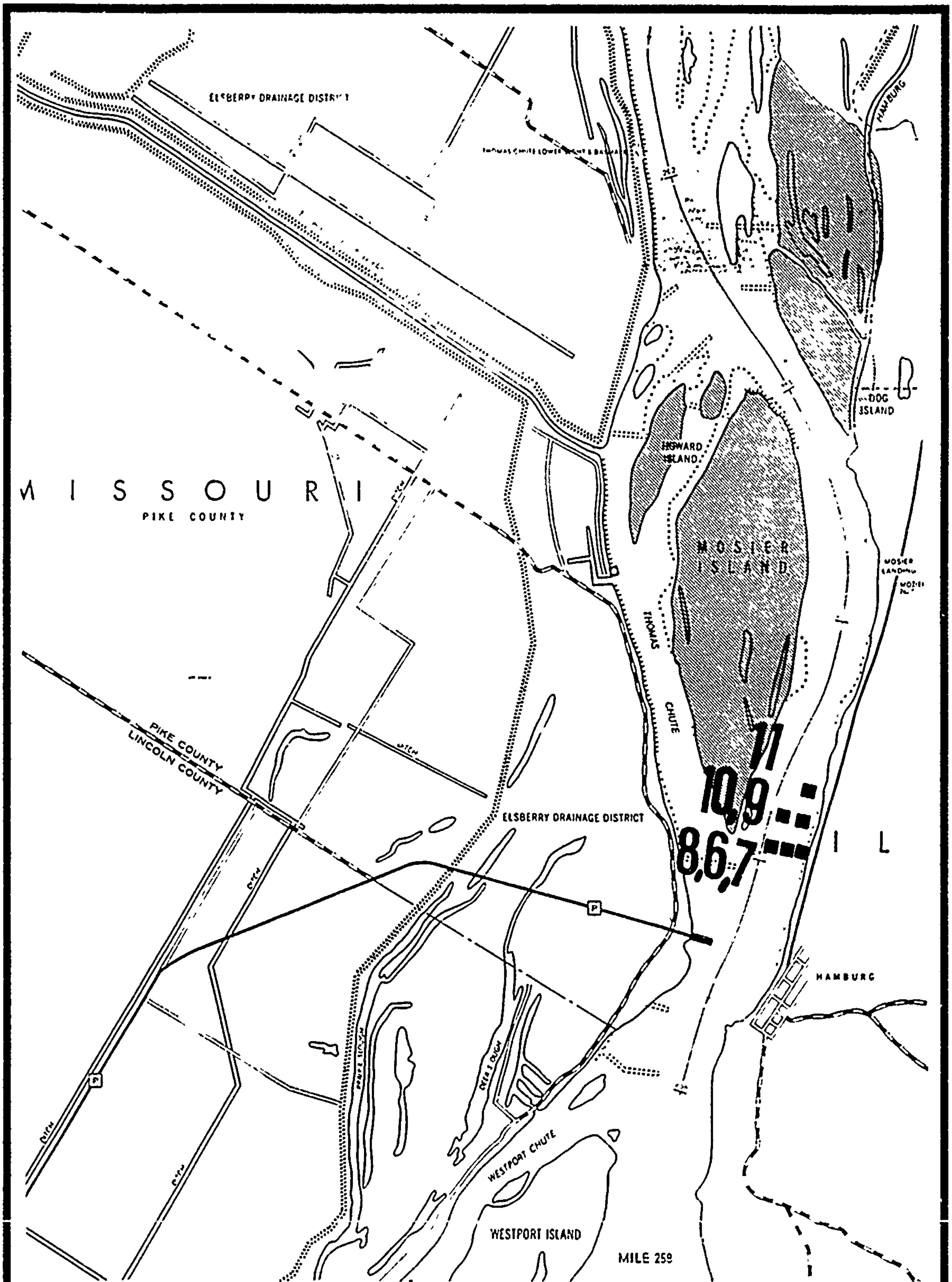
WINFIELD DRAINAGE AND LEVEE DISTRICT
4.
MISSOURI
LINCOLN COUNTY
HASTINGS LANDING
TURKEY ISLAND
ILLIN
CALHOUN COUNT
ARGENT SLOUGH
CUIVRE ISLAND
CUIVRE RIVER
LINCOLN COUNTY
ST CHARLES COUNTY
MONROE DISTRICT



STAR CITY
STERLING
OURI
COUNTY
FLAT POND
ERRY DRAINAGE DISTRICT
STERLING LANDING
MAPLE ISLAND
STAG ISLAND
KRIEGSVILLE
CAMPBELL'S ISLAND
LITTLE STAG ISLAND
KEETON ISLAND
KINGS LAKE
RAINAGE DISTRICT
5
ILLINOI
CALHOUN COUNTY
JIM CROW ISLAND
MILE 247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M I S S O U R I
PIKE COUNTY
PIKE COUNTY
LINCOLN COUNTY
ELSBERRY DRAINAGE DISTRICT
HOWARD ISLAND
MOSIER ISLAND
THOMAS CHUTE
DOG ISLAND
HAMBURG
11
10,9
8,6,7
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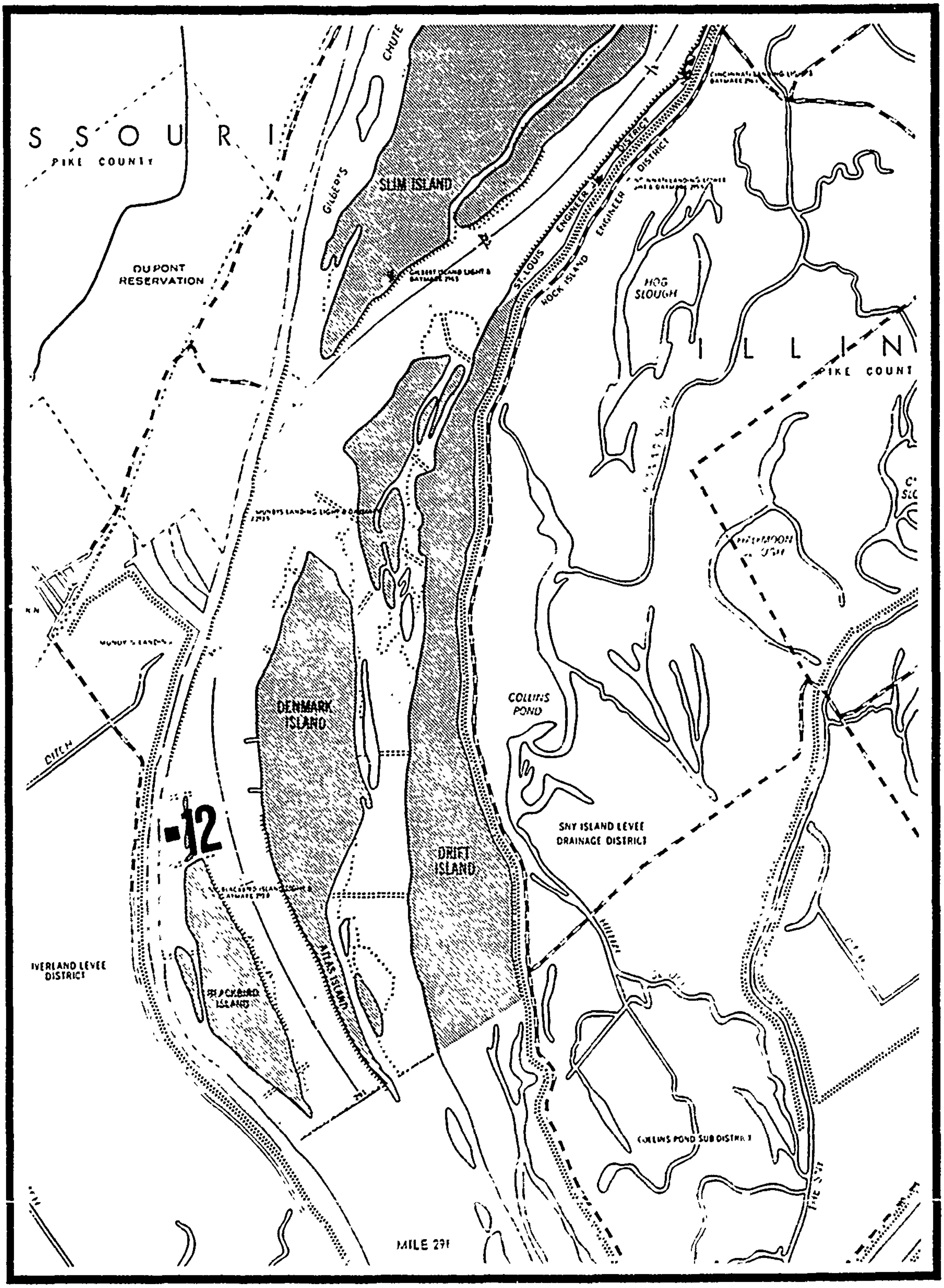
HAMBURG
WESTPORT CHUTE
WESTPORT ISLAND
MILE 259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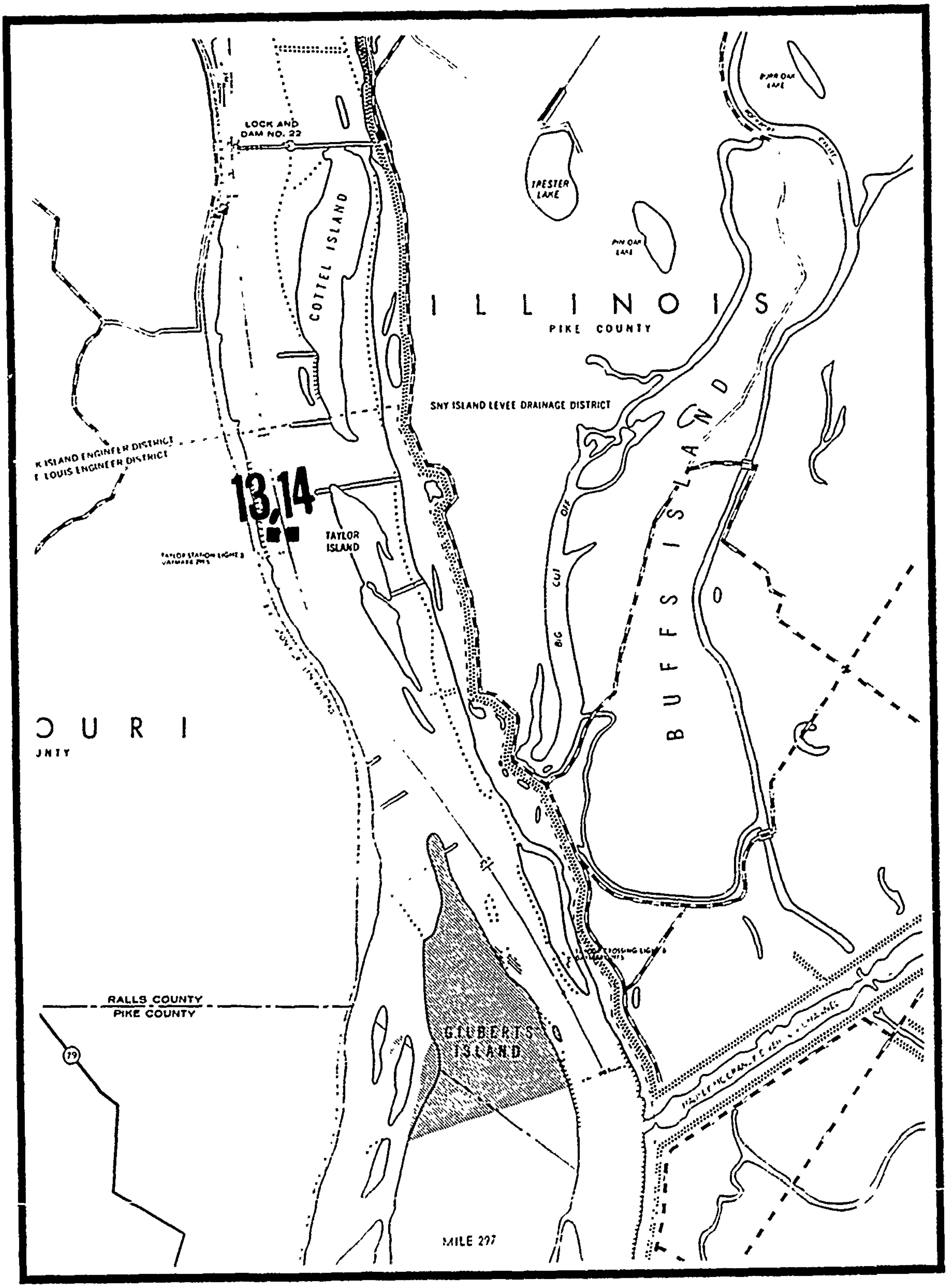
DU PONT RESERVATION
GILBERT'S CHUTE
SLIM ISLAND
ST. LOUIS ENGINEER DISTRICT
ROCK ISLAND ENGINEER DISTRICT
HOG SLOUGH
ILLIN
PIKE COUNT
DENMARK ISLAND
DRIFT ISLAND
COLLINS POND
SNY ISLAND LEVEE DRAINAGE DISTRICT
DITCH
12
IVERLAND LEVEE DISTRICT
BLACKBIRD ISLAND
ATLAS ISLAND
COLLINS POND SUB DISTRICT
MILE 291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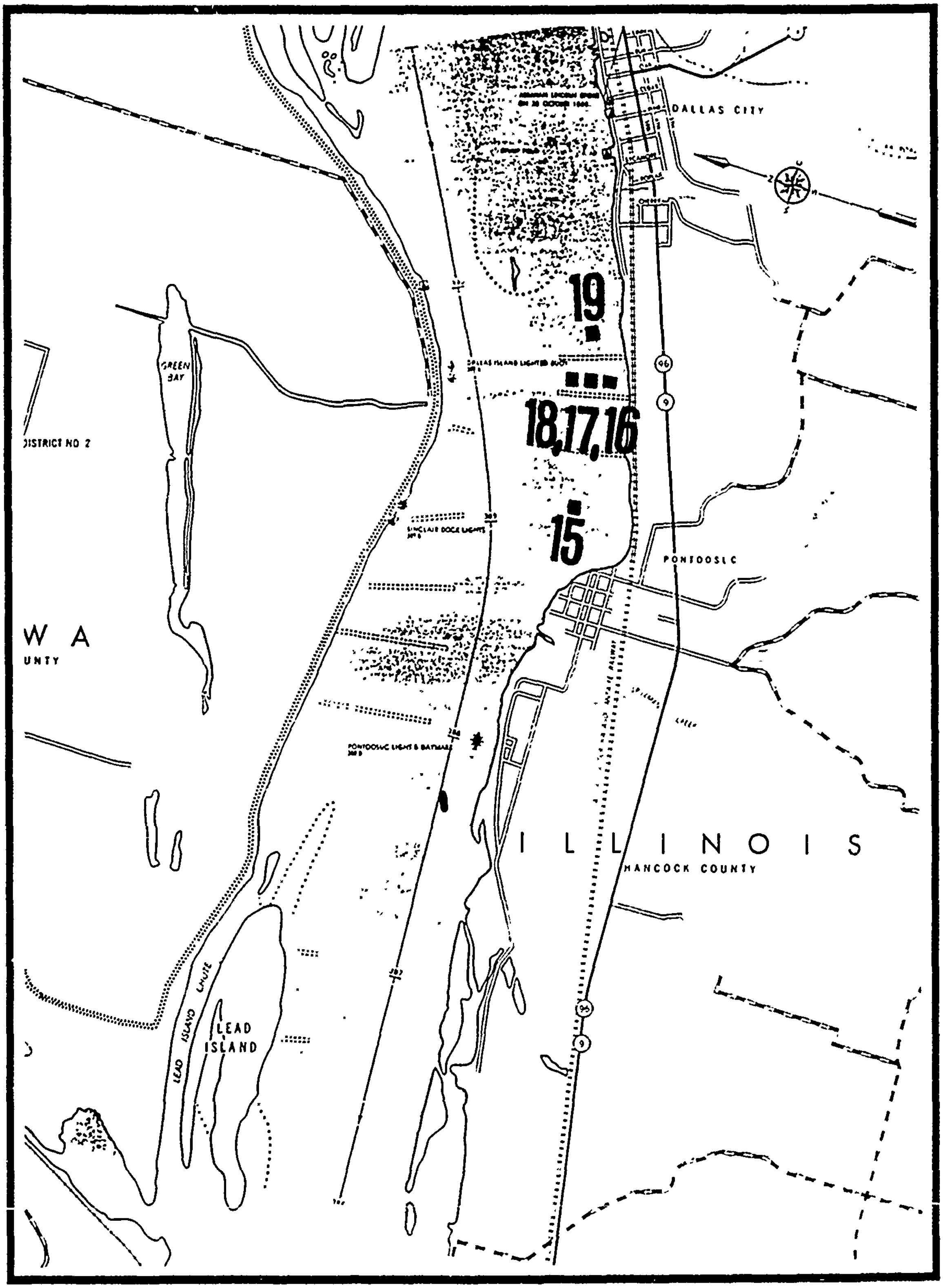
COTTEL ISLAND
TPESTER LAKE
ILLINOIS
PIKE COUNTY
SNY ISLAND LEVEE DRAINAGE DISTRICT
BIG CUT OFF
BUFFS ISLAND
13
14
TAYLOR ISLAND
OURI
JNTY
RALLS COUNTY
PIKE COUNTY
79
GILBERTS ISLAND
MILE 297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19
18,17,16
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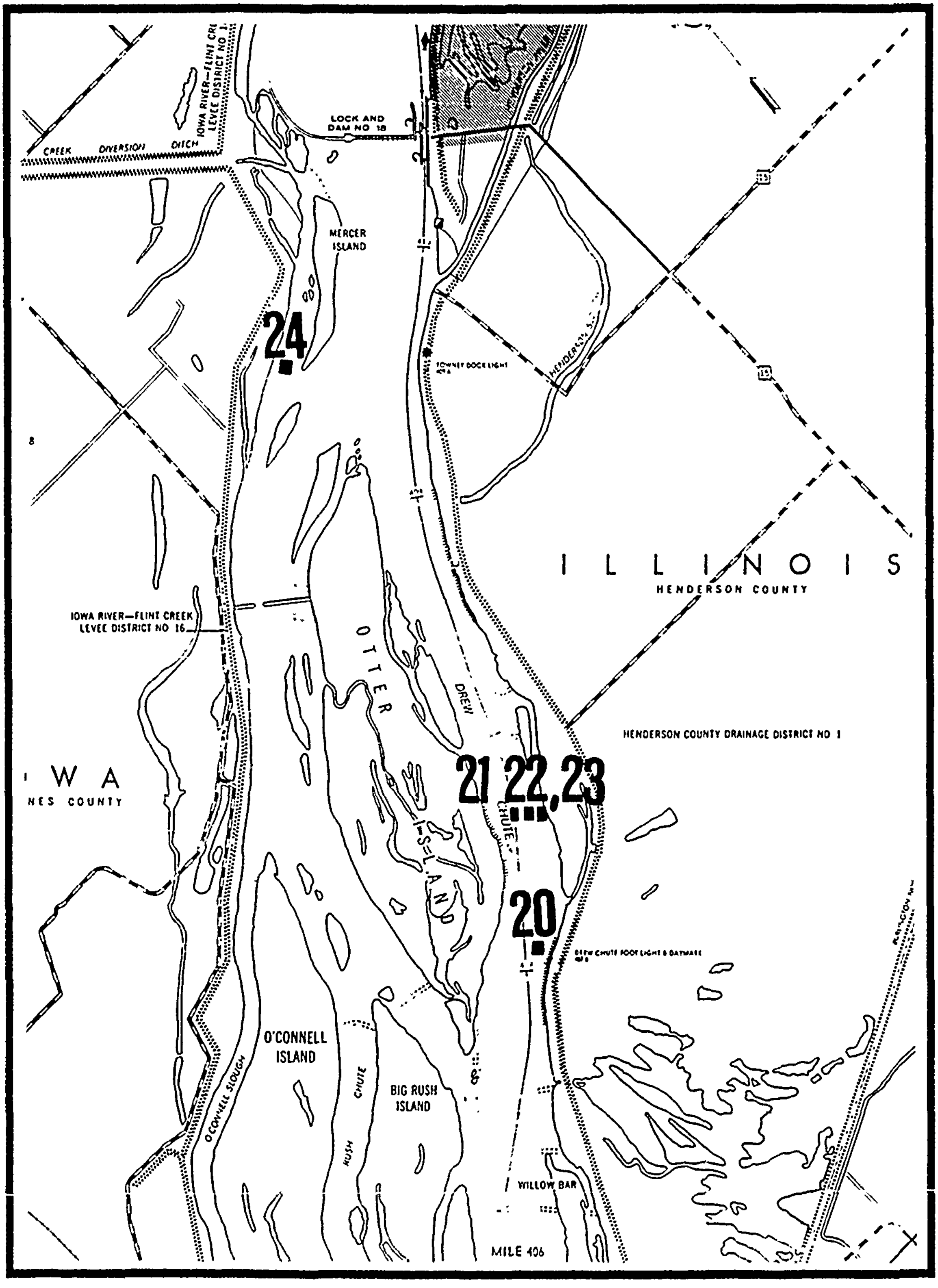
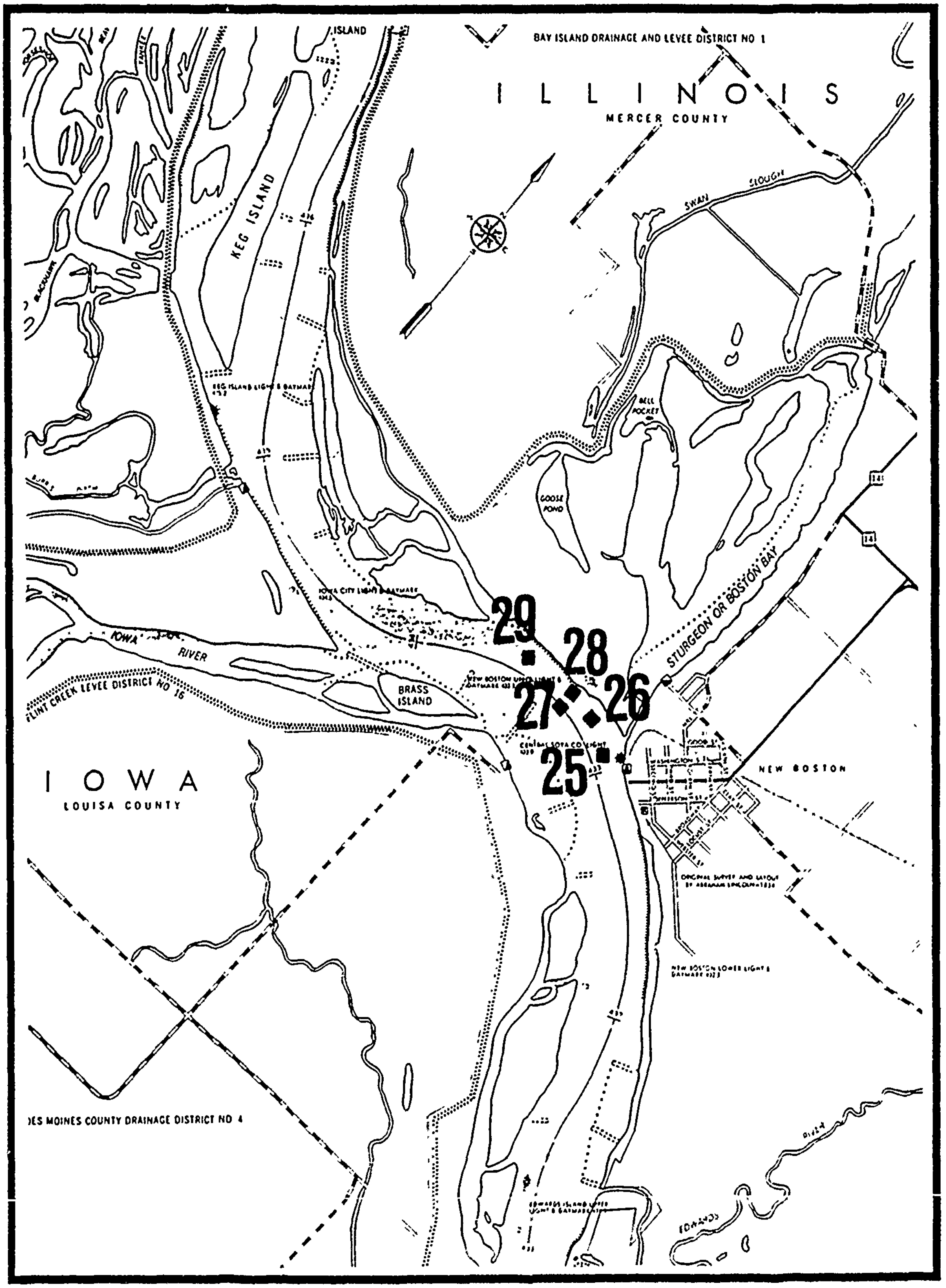
PONTOOSUC
ILLINOIS
HANCOCK COUNTY
GREEN BAY
DISTRICT NO 2
W A
UNTY
LEAD ISLAND
LEAD ISLAND CHUTE
96
9



IOWA RIVER—FLINT CREEK LEVEE DISTRICT NO 16
CREEK DIVERSION DITCH
LOCK AND DAM NO 18
MERCER ISLAND
24
ILLINOIS
HENDERSON COUNTY
IOWA RIVER—FLINT CREEK LEVEE DISTRICT NO 16
OTTER ISLAND
DREW CHUTE
HENDERSON COUNTY DRAINAGE DISTRICT NO 1
21 22,23
WA
NES COUNTY
20
O'CONNELL ISLAND
O'CONNELL SLOUGH
BIG RUSH ISLAND
RUSH CHUTE
WILLOW BAR
MILE 406


BAY ISLAND DRAINAGE AND LEVEE DISTRICT NO 1
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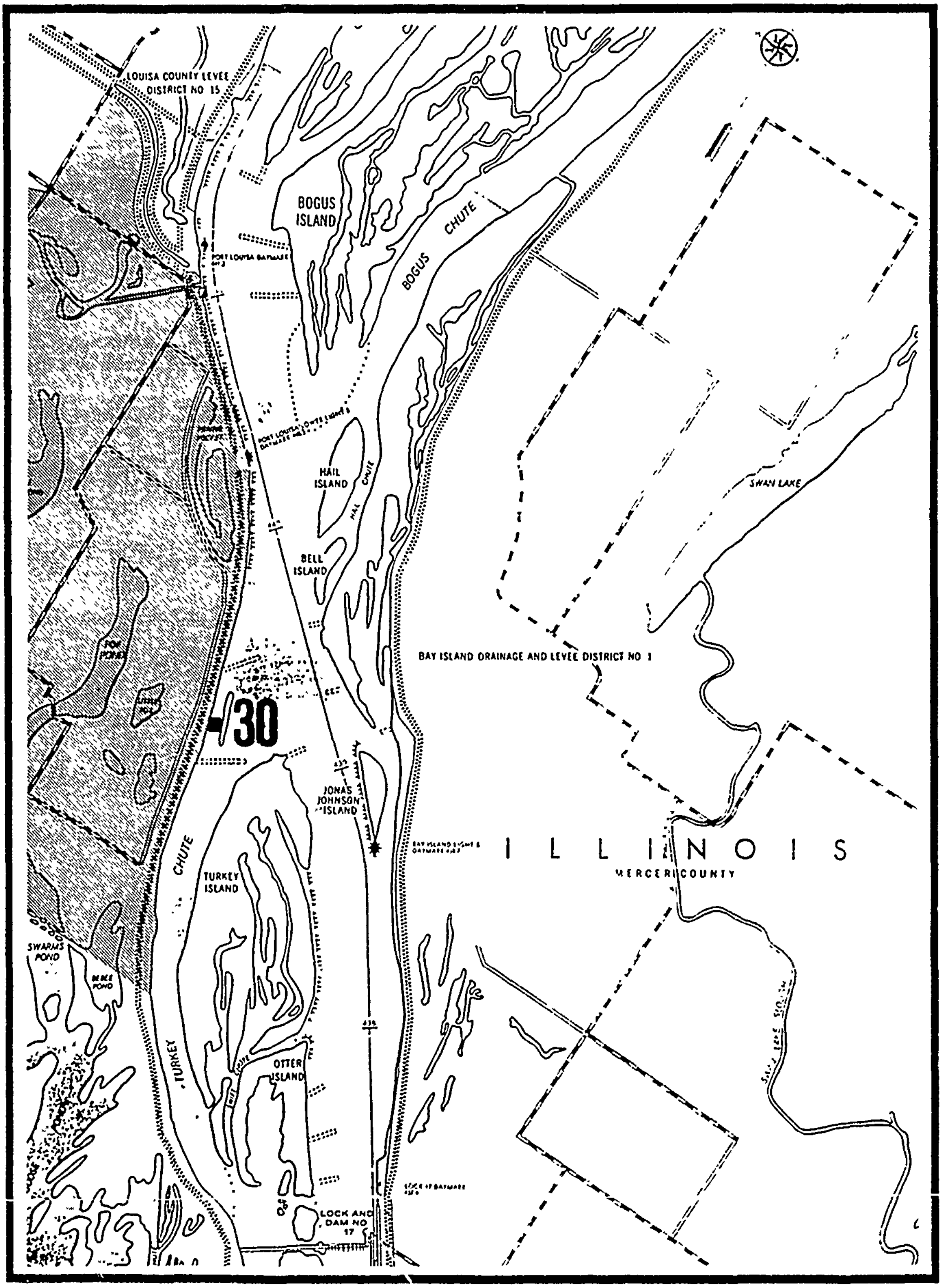
MERCER COUNTY
KEG ISLAND
SWAN SLOUGH
BELL POCKET
GOOSE POND
STURGEON OR BOSTON BAY
IOWA RIVER
BRASS ISLAND
FLINT CREEK LEVEE DISTRICT NO 16
29
28
27
26
25
NEW BOSTON
IOWA
LOUISA COUNTY
DES MOINES COUNTY DRAINAGE DISTRICT NO 4
EDWARDS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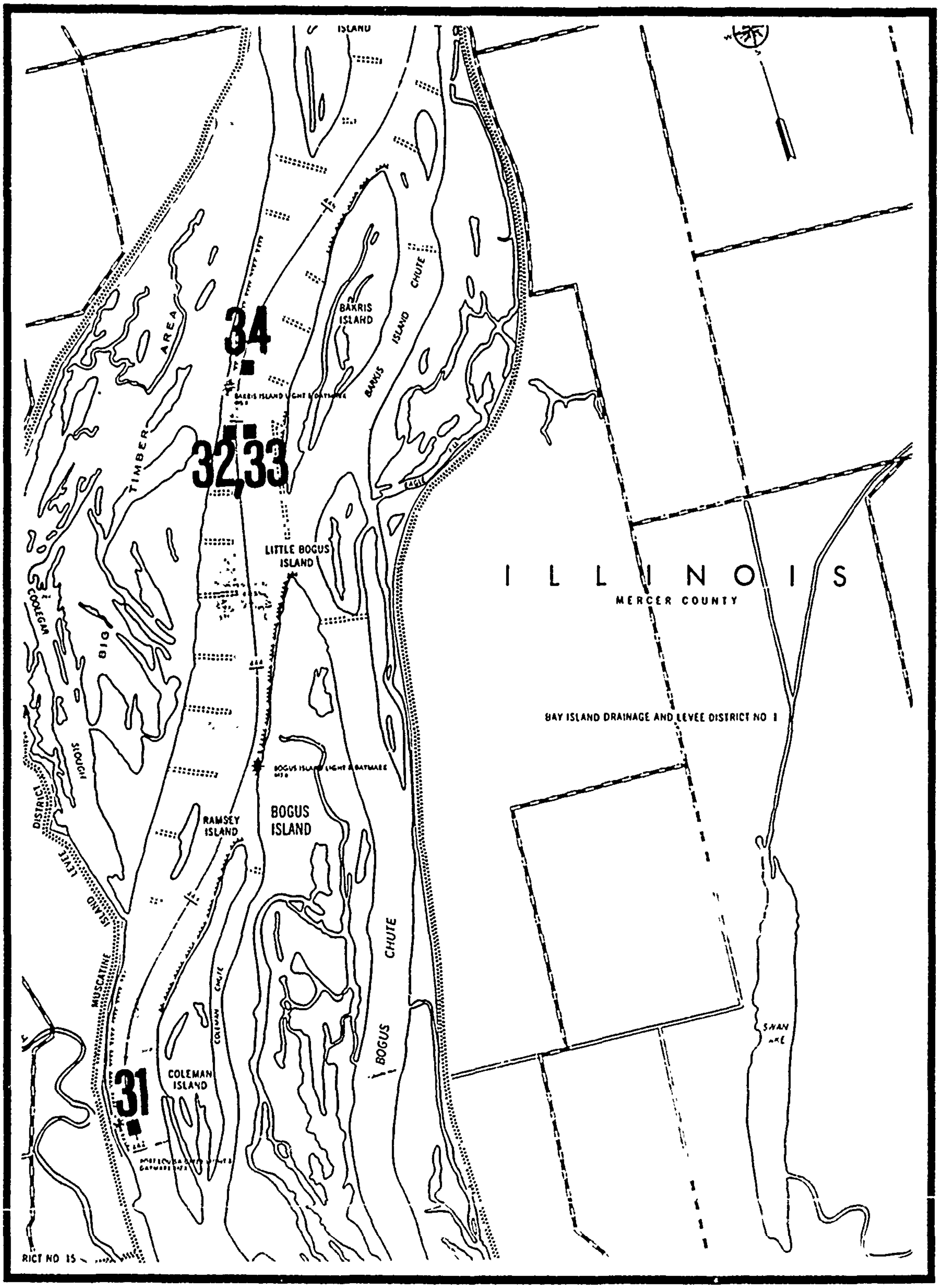
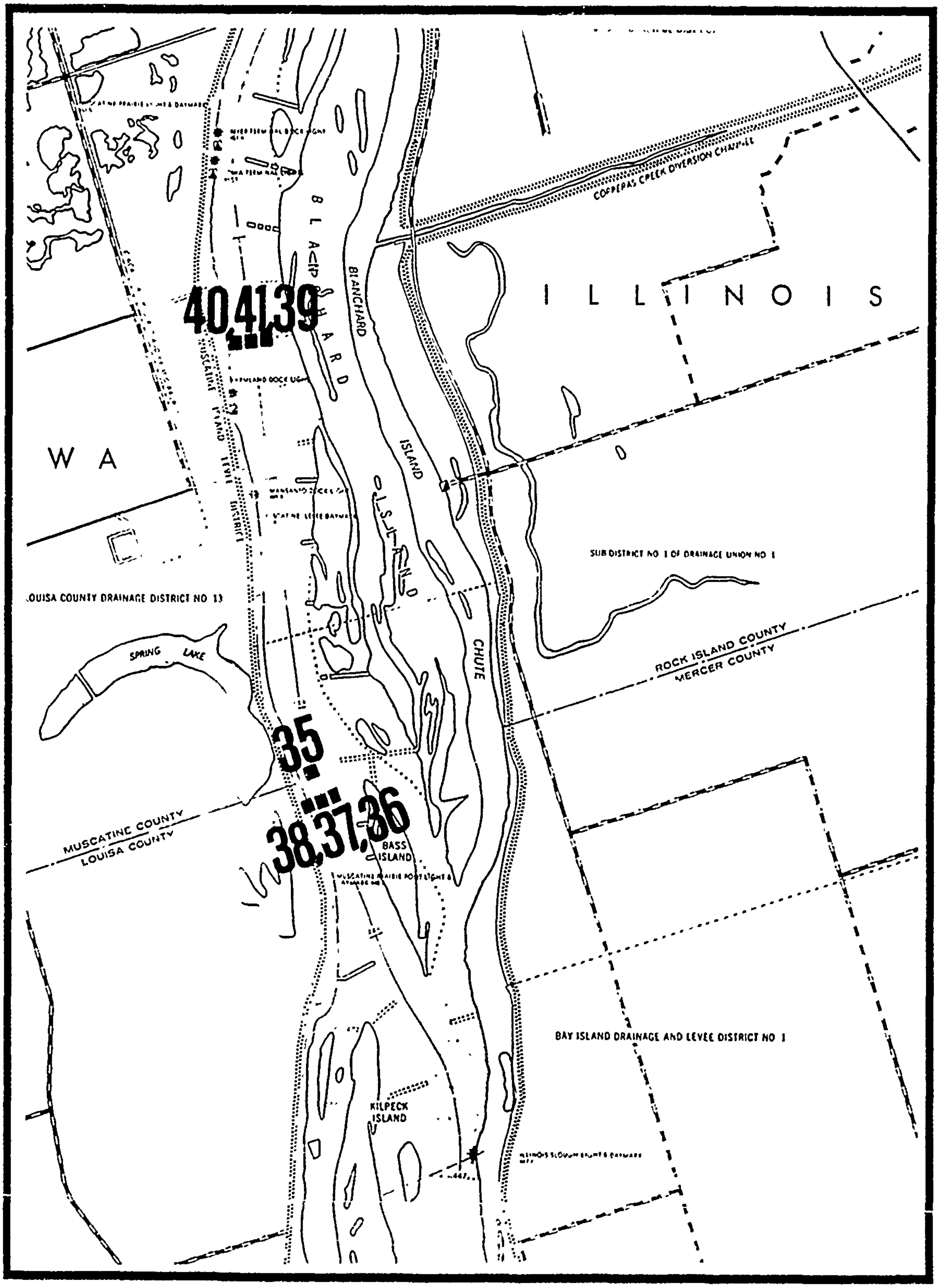
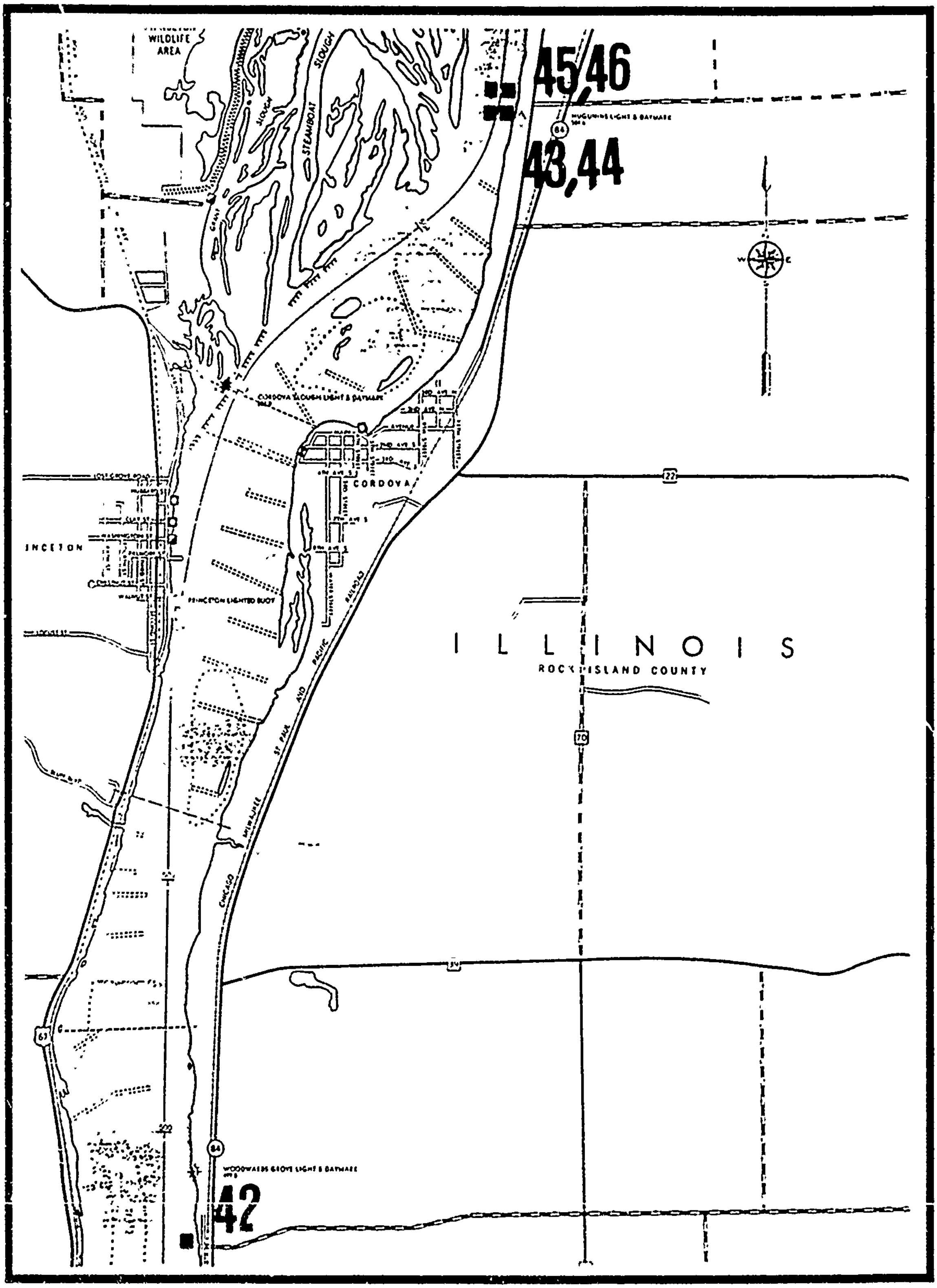
BOGUS ISLAND
BOGUS CHUTE
HAIL ISLAND
HAIL CHUTE
BELL ISLAND
SWAN LAKE
BAY ISLAND DRAINAGE AND LEVEE DISTRICT NO 1
30
JONAS JOHNSON ISLAND
ILLINOIS
MERCER COUNTY
TURKEY ISLAND
CHUTE
SWARMS POND
TURKEY
OTTER ISLAND
LOCK AND DAM NO 17



34
32,33
31
BAKRIS ISLAND
BAKRIS ISLAND CHUTE
LITTLE BOGUS ISLAND
RAMSEY ISLAND
BOGUS ISLAND
BOGUS CHUTE
COLEMAN ISLAND
COLEMAN CHUTE
TIMBER AREA
BIG
COOLEGAR
SLOUGH
MUSCATINE ISLAND LEVEE DISTRICT
ILLINOIS
MERCER COUNTY
BAY ISLAND DRAINAGE AND LEVEE DISTRICT NO 1


ILLINOIS
WA
COPPERAS CREEK DIVERSION CHANNEL
BLANCHARD
BLANCHARD ISLAND CHUTE
40,41,39
MUSCATINE ISLAND LEVEE DISTRICT
SUB DISTRICT NO 1 OF DRAINAGE UNION NO 1
LOUISA COUNTY DRAINAGE DISTRICT NO 13
SPRING LAKE
ROCK ISLAND COUNTY
MERCER COUNTY
35
38,37,36
BASS ISLAND
MUSCATINE COUNTY
LOUISA COUNTY
BAY ISLAND DRAINAGE AND LEVEE DISTRICT NO 1
KILPECK ISLAND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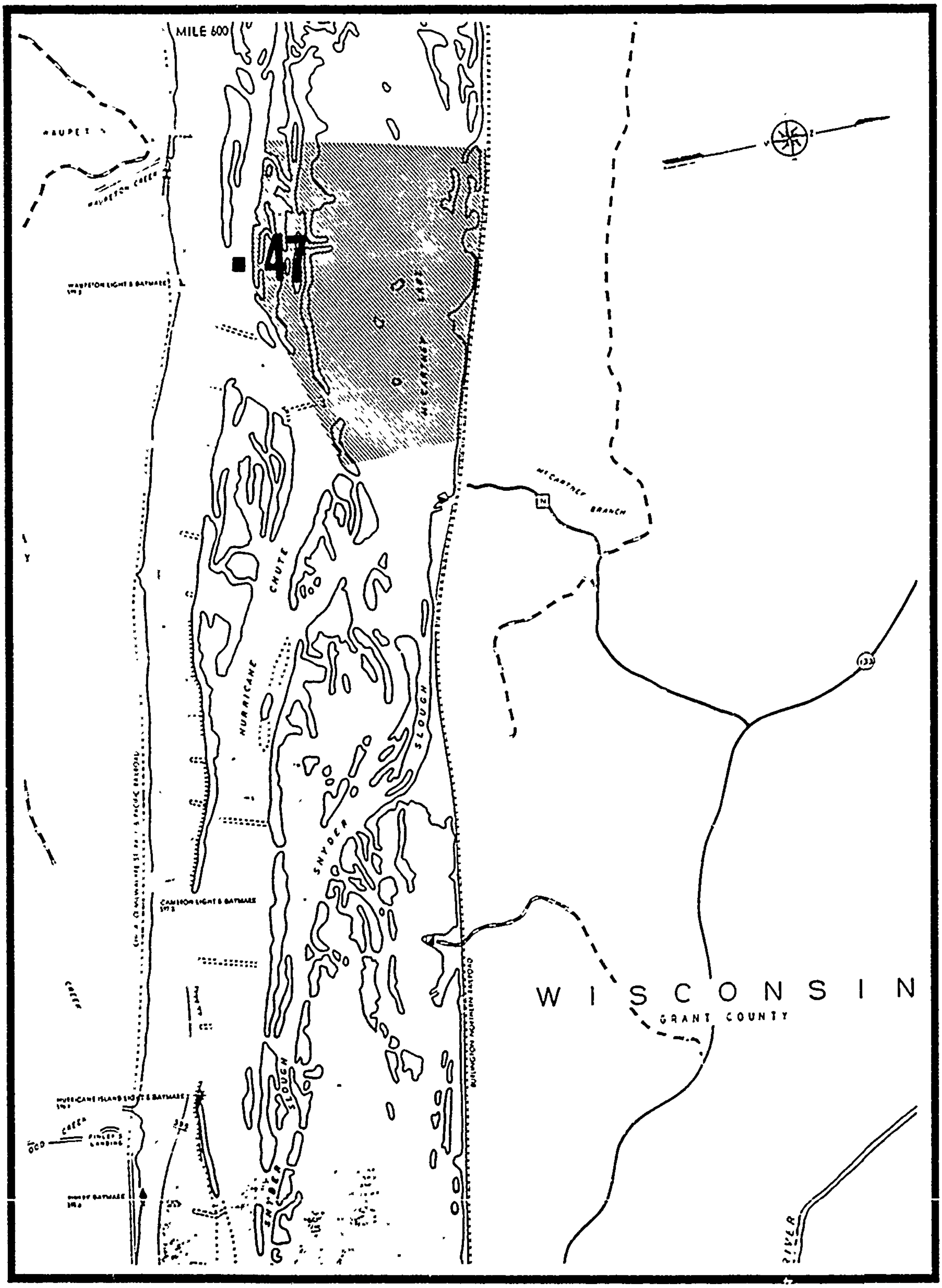
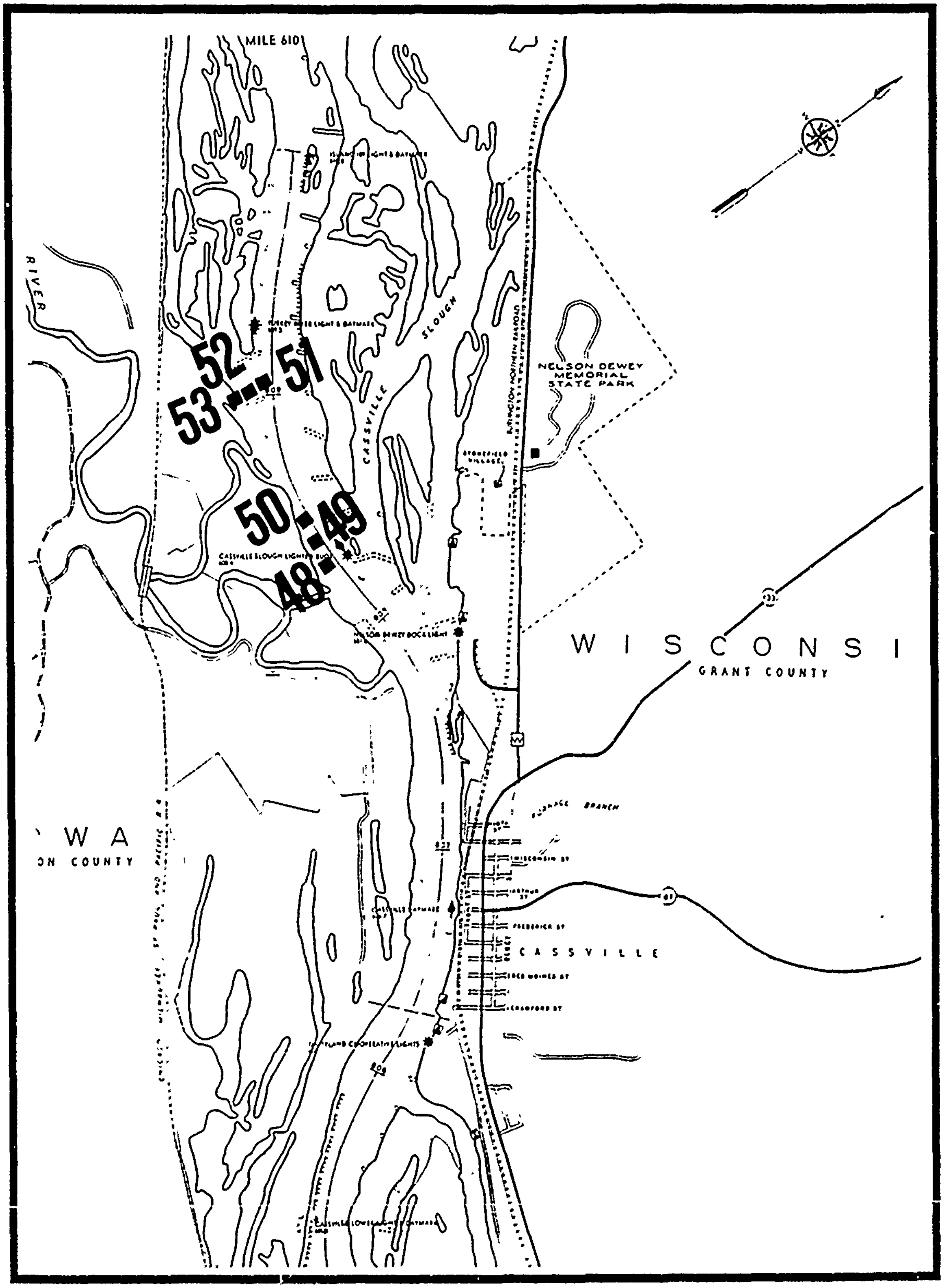
SLOUGH
STEAMBOAT SLOUGH
45,46
43,44
CORDOVA SLOUGH LIGHT & DAYMARK
CORDOVA
INCETON
PRINCETON LIGHTED BUOY
ILLINOIS
ROCK ISLAND COUNTY
CHICAGO MILWAUKEE ST PAUL AND PACIFIC RAILROAD
22
70
84
67
WOODWARDS GROVE LIGHT & DAYMARK
42



MILE 600
47
McCARTNEY LAKE
HURRICANE CHUTE
SNYDER SLOUGH
McCARTNEY BRANCH
WISCONSIN
GRANT COUNTY
RIVER


MILE 610
RIVER
CASSVILLE SLOUGH
NELSON DEWEY MEMORIAL STATE PARK
WISCONSI
GRANT COUNTY
CASSVILLE
WA
ON COUNTY
52
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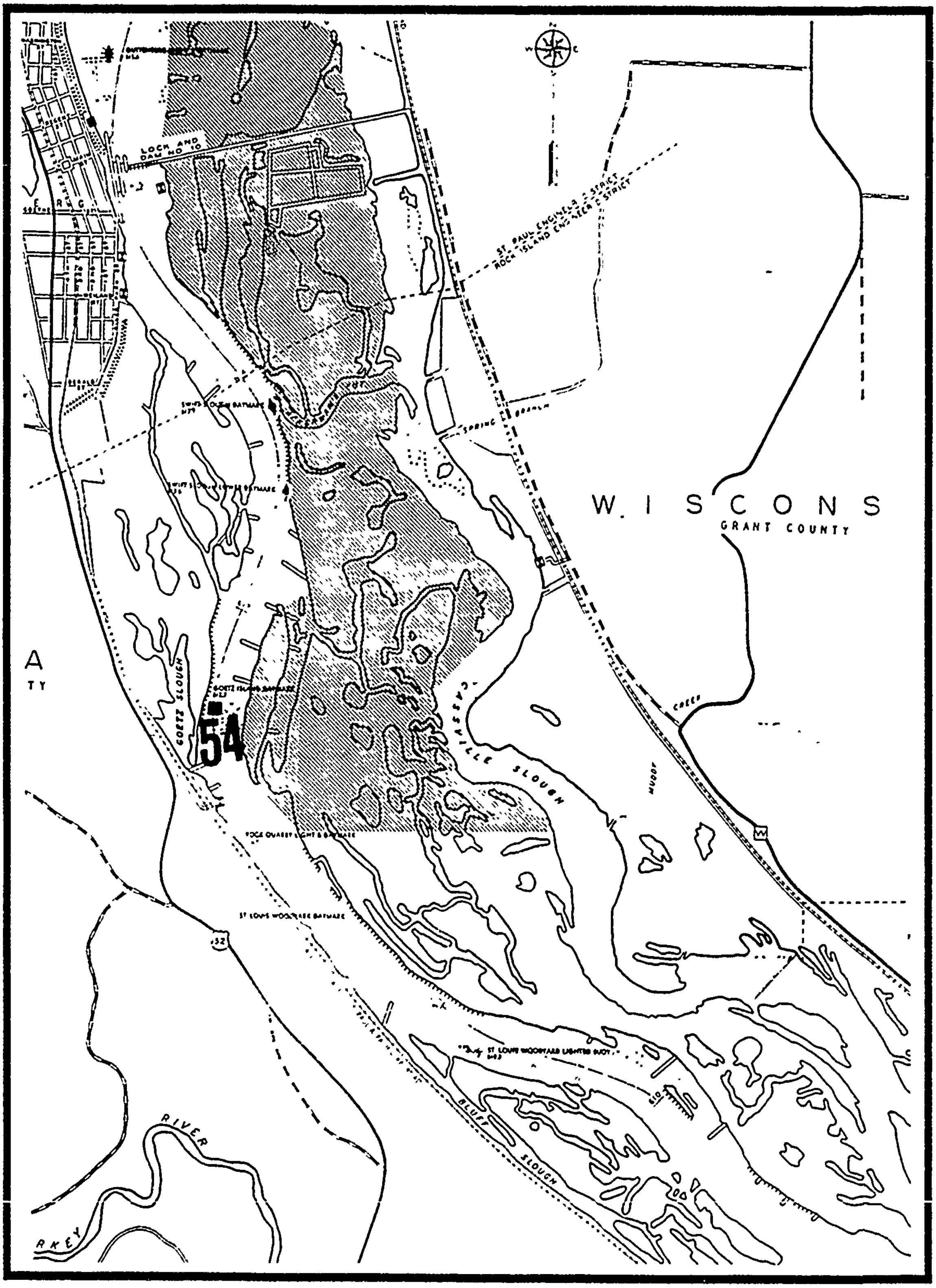
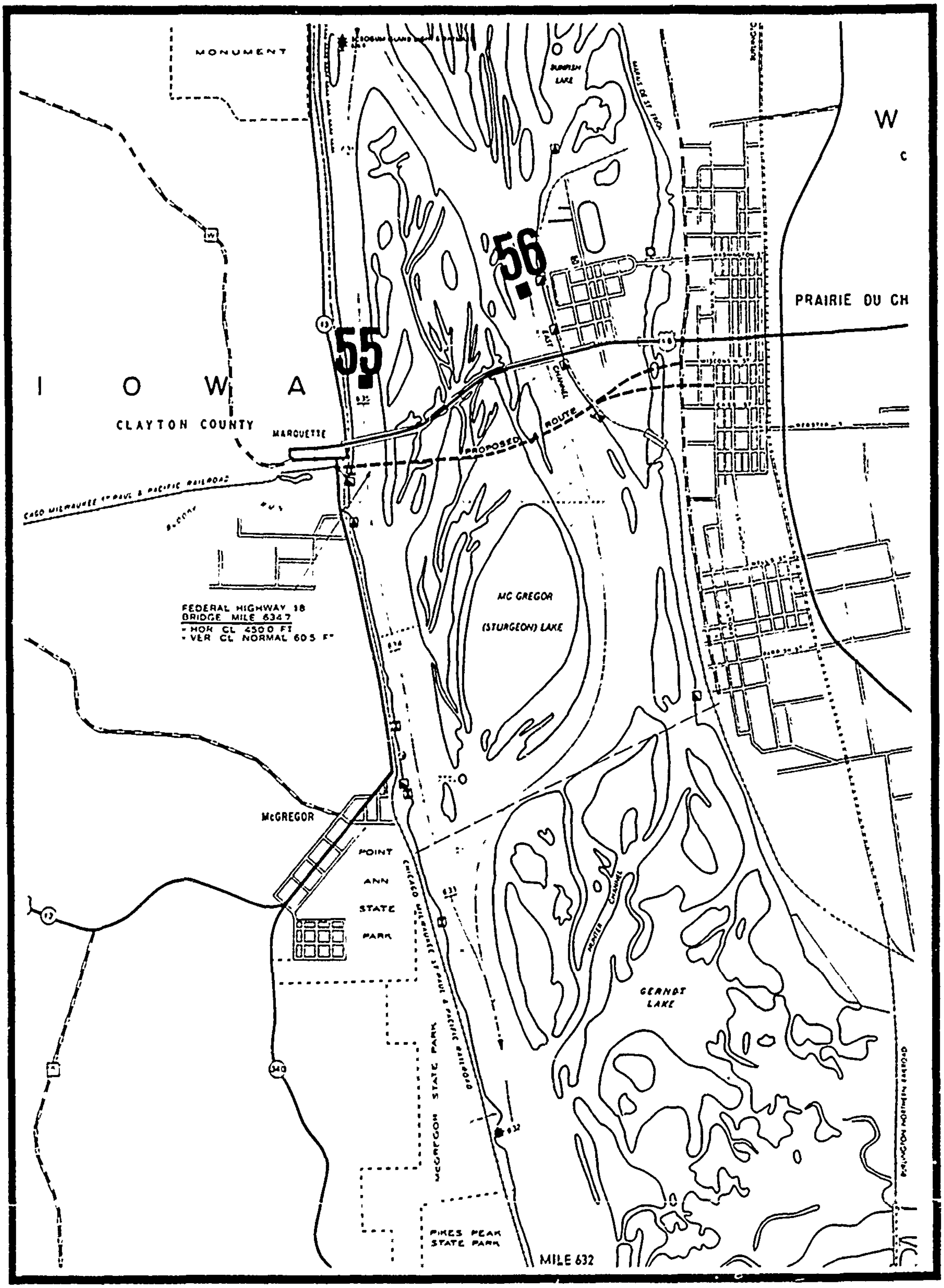
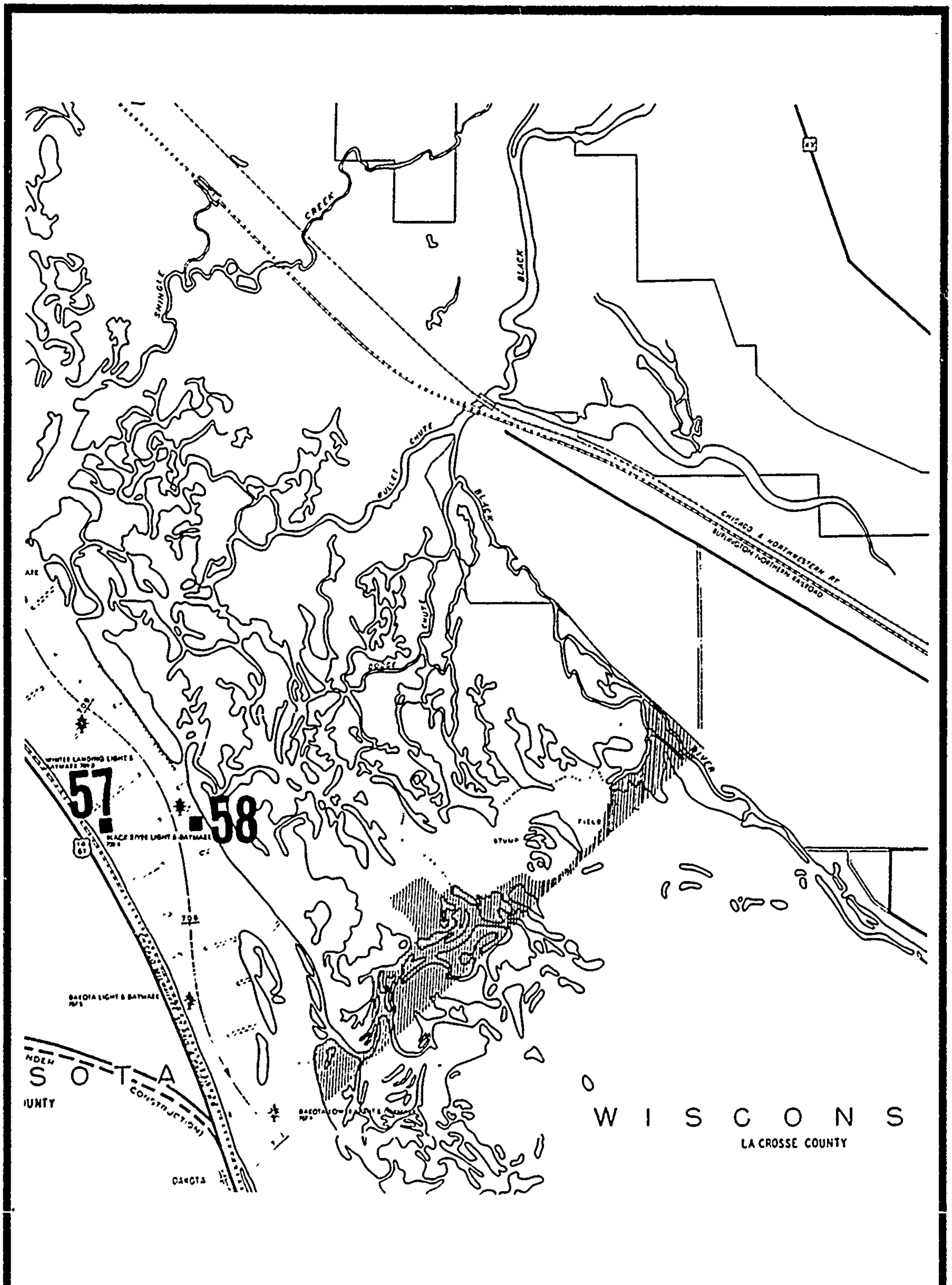
48


LOCK AND DAM NO 10
ST. PAUL ENGINEER DISTRICT
ROCK ISLAND ENGINEER DISTRICT
W I S C O N S
GRANT COUNTY
A
GOETZ SLOUGH
54
CASSVILLE SLOUGH
MUDDY
CREEK
ROCK QUARRY LIGHT & DAYMARK
ST LOUIS WOODYARD DAYMARK
ST LOUIS WOODYARD LIGHTED BUOY
BLUFF SLOUGH
RIVER
52



MONUMENT
W
PRAIRIE DU CH
I O W A
CLAYTON COUNTY
MARQUETTE
PROPOSED ROUTE
EAST CHANNEL
MC GREGOR (STURGEON) LAKE
FEDERAL HIGHWAY 18
BRIDGE MILE 634.7
HOR CL 450.0 FT
VER CL NORMAL 60.5 FT
McGREGOR
POINT ANN STATE PARK
McGREGOR STATE PARK
GERNDT LAKE
FRONTIER CHANNEL
PIKES PEAK STATE PARK
MILE 632
55
56



CREEK
SHINGLE
BLACK
BULLET CHUTE
CHICAGO & NORTHWESTERN RY
BURLINGTON NORTHERN RAILROAD
CHUTE
RIVER
57
58
FIELD
STUMP
SOTA
W I S C O N S
LA CROSSE COUNTY
DAKOTA

APPENDIX C

FRESHWATER BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER, 1987-88, USING QUALITATIVE TECHNIQUES

Table C1

Relative Species Abundance (Percentage) for Mussels Collected with Qualitative Techniques by Divers in the Upper Mississippi River, 1987-88*

Species	Relative Species Abundance (%)												
RM:	232	233	239	247	259	292	299	389	407	409	433	439	442
A. plicata	18.75	20.91	25.47	1.17	16.60	15.12	10.43	4.15	6.69	9.14	8.62	2.21	14.29
T. donaciformis	0.00	0.00	0.37	0.00	0.25	0.58	0.00	0.00	0.28	2.86	4.72	16.57	4.43
L. fragilis	16.25	4.55	3.75	29.24	6.46	0.00	3.37	18.24	10.24	1.14	5.64	13.81	14.29
P. alatus	6.25	2.42	1.50	7.02	13.05	0.00	0.92	3.86	5.83	4.00	0.72	6.08	9.36
Q. quadrula	5.00	12.12	10.49	5.26	9.89	3.49	7.06	4.92	5.55	0.57	4.31	0.00	0.99
T. truncata	1.25	5.15	1.12	11.11	8.37	14.53	5.21	2.32	8.11	1.71	21.03	2.76	18.23
A. confragosus	1.25	0.00	1.12	3.51	0.25	0.00	0.00	0.39	0.43	0.00	0.92	0.00	0.49
M. gigantea	31.25	6.36	3.75	0.58	7.73	0.00	9.82	1.16	2.99	0.00	0.82	0.00	0.49
O. reflexa	3.75	8.79	16.48	1.75	10.14	25.00	11.66	3.28	3.98	20.57	9.03	2.21	3.37
A. grandis	6.25	1.52	0.37	0.58	0.63	0.00	0.00	1.35	1.85	4.00	0.51	1.66	0.49
Q. nodulata	0.00	0.61	0.75	1.17	0.76	2.33	0.61	2.03	0.43	8.57	3.28	0.00	0.00
A. corpulenta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. pustulosa	1.25	7.27	1.87	1.75	2.79	9.88	7.36	4.34	13.80	17.14	24.51	2.21	5.42
T. parvus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E. lineolata	0.00	8.79	24.34	0.58	14.58	2.91	27.61	0.87	7.11	0.00	2.67	0.00	3.94
C. fluminea	3.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.00
F. flava	1.25	12.73	1.50	0.58	2.79	0.58	1.23	0.00	2.13	0.00	1.95	0.00	0.49
L. ventricosa	0.00	1.52	0.00	2.92	1.39	9.88	1.84	2.51	6.54	9.71	3.18	4.42	5.42
O. olivaria	1.25	4.85	3.75	16.96	2.79	15.12	7.67	4.15	16.07	17.71	4.31	36.46	0.99
P. laevissima	1.25	0.30	0.00	1.75	0.25	0.00	0.00	1.45	0.85	2.29	1.13	11.05	3.45
L. recta	0.00	0.00	0.00	0.00	0.13	0.00	1.23	0.77	1.42	0.00	0.10	0.00	2.96
S. undulatus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.14	0.00	0.31	0.00	0.99
L. higginsi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49
L. complanata	0.00	0.00	0.00	1.17	0.00	0.00	0.00	0.00	0.14	0.00	0.21	0.00	0.00
E. dilatata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L. teres	1.25	1.52	0.37	12.87	0.63	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00
Q. metanevra	0.00	0.00	1.87	0.00	0.38	0.00	3.37	0.48	3.41	0.57	1.03	0.00	0.00
A. ligamentina	0.00	0.30	0.75	0.00	0.00	0.00	0.00	1.06	1.71	0.00	0.92	0.00	1.48
L. radiata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00
C. monodonta	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.10	0.28	0.00	0.00	0.00	2.46
F. ebena	0.00	0.00	0.00	0.00	0.13	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00
A. imbecillis	0.00	0.00	0.00	0.00	0.00	0.58	0.00	41.99	0.00	0.00	0.10	0.00	0.49
P. cyphyus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P. sintoxia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. suborbiculata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Individuals	80	330	267	171	789	172	326	1036	703	175	975	181	203
% By Site	0.53	2.18	1.76	1.13	5.21	1.14	2.15	6.84	4.64	1.16	6.44	1.20	1.34

(Continued)

* Data under each column usually include multiple collections at more than one site. See Table 1 and the maps in Appendix B.

Table C1 (Concluded)

Species	RM:	Relative Species Abundance (%)											
		445	448	450	499	504	599	609	612	635*	635	708*	708
A. plicata		12.83	18.18	11.11	14.00	34.33	13.68	36.73	68.93	71.61	58.08	28.80	49.39
T. donaciformis		0.18	1.79	1.23	1.00	0.27	0.53	0.90	0.00	0.35	0.00	0.14	0.17
L. fragilis		13.37	11.29	10.93	1.50	2.32	0.53	0.41	0.00	1.10	0.57	2.40	0.17
P. alatus		7.31	7.30	6.00	4.00	5.86	3.16	1.64	0.00	4.00	0.57	0.81	9.19
Q. quadrula		3.74	2.89	1.76	6.50	6.68	5.79	2.88	1.13	2.00	4.86	0.19	0.00
T. truncata		6.06	3.31	5.64	29.00	4.90	17.37	13.31	7.34	2.85	1.43	0.77	0.35
A. confragosus		1.43	0.28	0.71	0.50	0.68	0.53	0.41	0.00	1.05	1.29	0.00	0.00
M. gigantea		3.74	1.24	2.65	6.50	1.77	1.05	1.31	0.00	4.25	1.43	0.00	0.00
O. reflexa		1.78	2.07	3.00	21.00	6.68	7.89	5.83	3.39	1.70	1.29	20.12	5.89
A. grandis		1.25	1.24	2.29	1.00	0.41	0.00	0.16	0.00	0.15	0.43	0.05	0.87
Q. nodulata		1.07	0.41	0.88	1.50	0.54	1.05	3.04	0.00	0.85	1.00	0.00	0.00
A. corpulenta		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. pustulosa		10.34	13.22	9.70	8.00	11.17	8.42	5.34	5.65	0.90	2.29	8.24	6.59
T. parvus		0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
E. lineolata		5.35	5.51	3.53	3.00	5.86	0.53	1.15	0.56	0.05	0.00	0.14	0.00
C. fluminea		0.00	0.69	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. flava		3.39	1.93	1.23	1.00	3.41	1.58	4.60	3.39	2.40	5.58	2.73	1.39
L. ventricosa		3.21	3.58	4.23	1.00	6.95	5.26	7.40	2.82	2.10	7.15	14.95	23.74
O. olivaria		4.63	7.44	8.11	0.00	3.13	26.32	5.83	4.52	1.40	5.29	18.35	1.21
P. laevissima		0.89	2.48	0.18	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.86	0.00
L. recta		1.43	1.10	0.18	0.00	3.27	1.58	2.22	0.56	1.10	2.86	0.34	0.87
S. undulatus		0.89	0.28	0.35	0.50	0.00	2.63	1.31	0.56	0.45	0.72	0.05	0.00
L. higginsi		0.00	0.00	0.18	0.00	1.09	0.00	0.66	0.00	0.65	1.72	0.10	0.00
L. complanata		0.36	0.28	0.00	0.00	0.14	0.53	0.25	0.56	0.25	1.00	0.24	0.00
E. dilatata		0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.45	0.29	0.00	0.00
L. teres		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. metanevra		2.14	3.44	6.88	0.00	0.54	0.53	2.63	0.56	0.30	2.00	0.34	0.00
A. ligamentina		3.21	2.89	1.41	0.00	0.00	1.05	0.25	0.00	0.00	0.14	0.05	0.00
L. radiata		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.05	0.00
C. monodonta		0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
F. ebena		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. imbecillis		11.23	7.02	17.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P. cyphyus		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00
P. sintoxia		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00
A. suborbiculata		0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Individuals		561	726	567	200	734	190	1217	177	2001	699	2087	577
% By Site		3.70	4.79	3.74	1.32	4.85	1.25	8.04	1.17	13.21	4.62	13.78	3.81

* Sampled in 1987; all other collections were made in 1988.

Table C2

Frequency of Occurrence (Percentage) for Mussels Collected with Qualitative Techniques by Divers in the Upper Mississippi River, 1987-88*

Species	Frequency of Occurrence (%)												
(RM)	232	233	239	247	259	292	299	389	407	409	433	439	442
A. plicata	85.71	90.00	88.24	25.00	92.86	100.00	83.33	56.82	66.67	77.78	71.11	22.22	100.00
T. donaciformis	0.00	0.00	5.88	0.00	4.76	11.11	0.00	0.00	5.56	33.33	46.67	44.44	77.78
L. fragilis	85.71	40.00	29.41	100.00	59.52	0.00	27.78	100.00	77.78	22.22	60.00	100.00	77.78
P. alatus	57.14	35.00	17.65	87.50	88.10	0.00	16.67	52.27	66.67	44.44	15.56	66.67	55.56
Q. quadrula	42.86	85.00	76.47	50.00	85.71	55.56	72.22	52.27	63.89	11.11	55.56	0.00	11.11
T. truncata	14.29	60.00	17.65	87.50	64.29	100.00	55.56	38.64	72.22	33.33	88.89	55.56	88.89
A. confragosus	14.29	0.00	17.65	50.00	4.76	0.00	0.00	9.09	8.33	0.00	17.78	0.00	11.11
M. gigantea	100.00	55.00	47.06	12.50	57.14	0.00	66.67	20.45	41.67	0.00	15.56	0.00	11.11
O. reflexa	28.57	60.00	100.00	37.50	76.19	100.00	88.89	40.91	47.22	88.89	82.22	22.22	55.56
A. grandis	28.57	20.00	5.88	12.50	9.52	0.00	0.00	25.00	27.78	66.67	8.89	33.33	11.11
Q. nodulata	0.00	10.00	5.88	25.00	9.52	22.22	5.56	34.09	8.33	100.00	35.56	0.00	0.00
A. corpulenta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. pustulosa	14.29	70.00	29.41	37.50	45.24	77.78	61.11	56.82	86.11	100.00	95.56	22.22	77.78
T. parvus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E. lineolata	0.00	65.00	94.12	12.50	85.71	22.22	94.44	15.91	75.00	0.00	37.78	0.00	77.78
C. fluminea	14.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.11	0.00
F. flava	14.29	70.00	23.53	12.50	33.33	11.11	16.67	0.00	36.11	0.00	35.56	0.00	11.11
L. ventricosa	0.00	25.00	0.00	37.50	21.43	100.00	33.33	31.82	77.78	88.89	51.11	55.56	77.78
O. olivaria	14.29	35.00	41.18	100.00	33.33	100.00	77.78	27.27	97.22	88.89	46.67	100.00	22.22
P. laevissima	14.29	5.00	0.00	37.50	4.76	0.00	0.00	27.27	13.89	22.22	15.56	66.67	33.33
L. recta	0.00	0.00	0.00	0.00	2.38	0.00	16.67	11.36	22.22	0.00	2.22	0.00	33.33
S. undulatus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27	2.78	0.00	6.67	0.00	22.22
L. higginsi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.11
L. complanata	0.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	2.78	0.00	4.44	0.00	0.00
E. dilatata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L. teres	14.29	25.00	5.88	100.00	9.52	0.00	0.00	4.55	0.00	0.00	0.00	0.00	0.00
Q. metanevra	0.00	0.00	17.65	0.00	7.14	0.00	38.89	6.82	44.44	11.11	17.78	0.00	0.00
A. ligamentina	0.00	5.00	11.76	0.00	0.00	0.00	0.00	15.91	30.56	0.00	20.00	0.00	33.33
L. radiata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.55	0.00	0.00	0.00	0.00	0.00
C. monodonta	0.00	0.00	5.88	0.00	0.00	0.00	0.00	2.27	5.56	0.00	0.00	0.00	44.44
F. ebena	0.00	0.00	0.00	0.00	2.38	0.00	11.11	0.00	0.00	0.00	0.00	0.00	0.00
A. imbecillis	0.00	0.00	0.00	0.00	0.00	11.11	0.00	81.82	0.00	0.00	2.22	0.00	11.11
P. cyphyus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P. sintoxia	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. suborbiculata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Samples	7	20	17	8	42	9	18	44	36	9	45	9	9

* Data under each column usually include multiple collections at more than one site. See Table 1 and the maps in Appendix B.

Table C2 (Concluded)

Species RM:	445	448	450	499	504	599	609	612	635*	635	708*	708
	Frequency of Occurrence (%)											
A. plicata	100.00	91.43	77.78	100.00	97.22	66.67	100.00	100.00	100.00	97.67	93.75	96.88
T. donaciformis	3.70	14.29	18.52	11.11	5.56	11.11	20.37	0.00	8.64	0.00	9.38	3.13
L. fragilis	96.30	77.14	70.37	33.33	41.67	11.11	9.26	0.00	20.99	9.30	59.38	3.13
P. alatus	77.78	65.71	59.26	55.56	63.89	55.56	29.63	0.00	48.15	9.30	25.00	50.00
Q. quadrula	55.56	34.29	25.93	77.78	75.00	88.89	50.00	22.22	27.16	48.84	12.50	0.00
T. truncata	55.56	48.57	55.56	100.00	50.00	100.00	92.59	55.56	38.27	18.60	18.75	6.25
A. confragosus	18.52	5.71	14.81	11.11	13.89	11.11	9.26	0.00	20.99	20.93	0.00	0.00
M. gigantea	48.15	22.86	37.04	77.78	27.78	11.11	25.93	0.00	50.62	18.60	0.00	0.00
O. reflexa	18.52	31.43	51.85	100.00	61.11	77.78	64.81	44.44	22.22	18.60	100.00	28.13
A. grandis	18.52	20.00	40.74	22.22	8.33	0.00	3.70	0.00	3.70	6.98	3.13	15.63
Q. nodulata	18.52	8.57	18.52	22.22	11.11	11.11	37.04	0.00	13.58	13.95	0.00	0.00
A. corpulenta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. pustulosa	88.89	82.86	92.59	88.89	83.33	77.78	70.37	66.67	17.28	30.23	87.50	65.63
T. parvus	0.00	0.00	0.00	0.00	0.00	0.00	7.41	0.00	0.00	0.00	0.00	0.00
E. lineolata	59.26	65.71	48.15	66.67	69.44	11.11	22.22	11.11	1.23	0.00	9.38	0.00
C. fluminea	0.00	8.57	3.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. flava	44.44	28.57	22.22	22.22	47.22	33.33	44.81	44.44	46.91	62.79	56.25	15.63
L. ventricosa	51.85	51.43	48.15	22.22	69.44	88.89	75.93	33.33	39.51	53.49	96.88	93.75
O. olivaria	59.26	62.86	74.07	0.00	50.00	100.00	70.37	44.44	20.99	44.19	93.75	15.63
P. laevissima	18.52	22.86	3.70	0.00	0.00	0.00	5.56	0.00	0.00	0.00	12.50	0.00
L. recta	25.93	22.86	3.70	0.00	52.78	22.22	33.33	11.11	22.22	34.88	15.63	15.63
S. undulatus	18.52	5.71	7.41	11.11	0.00	33.33	20.37	11.11	9.88	11.63	3.13	0.00
L. higginsi	0.00	0.00	3.70	0.00	22.22	0.00	14.81	0.00	13.58	25.58	6.25	0.00
L. complanata	7.41	5.71	0.00	0.00	2.78	11.11	5.56	11.11	6.17	13.95	6.25	0.00
E. dilatata	0.00	0.00	0.00	0.00	0.00	0.00	24.07	0.00	11.11	4.65	0.00	0.00
L. teres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q. metanevra	37.04	45.71	55.56	0.00	11.11	11.11	42.59	11.11	6.17	23.26	18.75	0.00
A. ligamentina	48.15	45.71	25.93	0.00	0.00	22.22	5.56	0.00	0.00	2.33	3.13	0.00
L. radiata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.00	3.13	0.00
C. monodonta	3.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.13
F. ebena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. imbecillis	70.37	51.43	88.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P. cyphyus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.38	0.00
P. sintoxia	0.00	0.00	0.00	0.00	0.00	0.00	3.70	0.00	0.00	0.00	3.13	0.00
A. suborbiculata	0.00	2.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Samples	27	35	27	9	36	9	54	9	81	43	32	32

* Sampled in 1987; all other collections were made in 1988.

APPENDIX D

RESULTS OF QUANTITATIVE SAMPLING IN THE UPPER MISSISSIPPI RIVER, 1988

Table D1

Relative Species Abundance of Mussels Collected in Ten 0.25-m^2 Samples in the Mississippi River, Mile 299.6, 20 July 1988

Species	Percentage
T. truncata	34.61
O. reflexa	17.95
E. lineolata	16.67
T. donaciformis	7.69
L. fragilis	5.13
Q. pustulosa	5.13
Q. quadrula	5.13
A. plicata	2.56
F. flava	1.28
L. recta	1.28
P. alatus	1.28
C. fluminea	1.28
Total individuals	78
Total species	12

Table D2

Relative Species Abundance of Mussels Collected in Twenty 0.25-m^2 Samples in the Mississippi River, Mile 389.5, 21 July 1988

Species	Percentage		
	Nearshore	Offshore	Total
A. imbecillis	63.13	--	55.86
L. fragilis	13.25	11.86	13.09
A. ligamentina	0.22	0.59	0.59
A. plicata	2.43	11.86	3.52
E. lineolata	0.66	1.69	0.78
A. grandis	0.22	--	0.20
A. confragosus	0.22	--	0.20
L. ventricosa	0.22	11.86	1.56
L. recta	0.22	--	0.20
C. monodonta	1.32	1.69	1.37
M. gigantea	2.87	--	2.54
P. alatus	2.87	--	2.54
O. olivaria	0.22	33.90	4.10
Q. pustulosa	2.87	8.47	3.52
P. laevissima	0.22	--	0.20
Q. nodulata	1.10	1.69	1.17
Q. quadrula	3.97	3.39	3.91
T. donaciformis	0.44	--	0.39
T. truncata	3.09	--	2.73
Total individuals	453	59	512
Total species	19	10	19

Table D3

Relative Species Abundance of Mussels Collected in Ten 0.25-m^2 Samples in the Mississippi River, Mile 409.5, 22 July 1988

Species	Percentage
A. plicata	23.07
A. grandis	7.69
L. ventricosa	7.69
L. fragilis	7.69
O. reflexa	15.38
O. olivaria	15.38
Q. metanevra	7.69
Q. nodulata	15.38
Total individuals	13
Total species	8

Table D4

Relative Species Abundance of Mussels Collected in Twenty 0.25-m^2 Samples in the Mississippi River, Mile 433.3, 23 July 1988

	Percentage		
Species	Nearshore	Offshore	Total
A. imbecillis	0.29	--	0.23
L. fragilis	2.59	3.41	2.75
A. ligamentina	0.29	--	0.23
A. plicata	2.87	9.09	4.13
D. lineolata	--	5.75	4.59
A. grandis	0.29	--	0.23
A. confragosus	0.29	--	0.23
L. ventricosa	0.29	2.27	0.69
L. recta	0.29	--	0.23
M. gigantea	0.86	--	0.69
O. olivaria	3.74	12.50	5.50
Q. pustulosa	21.84	21.84	23.17
P. laevissima	--	1.14	0.23
Q. nodulata	0.57	--	0.46
Q. quadrula	8.91	4.55	8.03
T. donaciformis	4.89	9.09	5.73
T. truncata	50.52	14.77	35.32
F. flava	1.15	3.41	1.61
L. complanata	0.29	--	0.23
O. reflexa	3.16	7.95	4.13
Q. metanevra	1.15	3.41	1.61
Total individuals	348	88	436
Total species	19	13	21

Table D5

Relative Species Abundance of Mussels Collected in Twenty 0.25-m^2 Samples in the Mississippi River, Mile 450.4, 25 July 1988

Species	Percentage Nearshore	Offshore	Total
A. imbecillis	31.93	30.32	31.46
L. fragilis	12.00	14.29	12.67
A. ligamentina	0.48	--	0.34
A. plicata	8.04	8.75	8.25
E. lineolata	5.16	2.62	4.42
A. grandis	0.60	0.87	0.68
L. ventricosa	0.24	0.29	0.26
M. gigantea	0.96	1.75	1.19
O. olivaria	1.20	1.46	1.28
A. suborbiculata	--	0.29	0.09
Q. pustulosa	4.20	7.87	5.37
P. laevissima	0.36	0.29	0.34
Q. nodulata	0.36	--	0.26
Q. quadrula	1.20	0.58	1.02
T. donaciformis	9.48	6.12	8.50
T. truncata	16.93	12.24	15.56
F. flava	0.36	0.87	0.51
L. complanata	0.24	0.29	0.26
O. reflexa	2.88	2.62	2.81
Q. metanevra	0.36	2.33	0.94
P. alatus	2.40	5.25	3.23
S. undulatus	0.60	0.87	0.68
Total individuals	833	343	1,176
Total species	21	20	22

Table D6

Relative Species Abundance of Mussels Collected in Twenty 0.25-m^2 Samples in the Mississippi River, Mile 504.7, 26 July 1988

Species	Percentage Nearshore	Offshore	Total
A. imbecillis	0.91	--	0.40
L. fragilis	2.73	6.99	5.14
A. ligamentina	--	0.70	0.40
A. plicata	25.45	9.79	16.60
E. lineolata	7.27	4.20	3.56
L. ventricosa	3.64	4.20	3.95
M. gigantea	--	1.40	0.79
O. olivaria	--	4.90	2.77
Q. pustulosa	10.00	10.49	10.28
Q. nodulata	0.91	0.70	0.79
Q. quadrula	7.27	4.20	5.53
T. donaciformis	2.73	13.29	8.70
T. truncata	20.00	18.88	19.37
F. flava	0.91	3.50	2.37
L. higginsi	.91	--	0.40
O. reflexa	8.18	12.59	10.67
P. alatus	2.73	3.50	3.16
C. parva	1.82	--	0.79
L. recta	1.82	0.70	1.19
C. fluminea	7.27	--	3.16
Total individuals	110	143	253
Total species	17	16	20

Table D7

Relative Species Abundance of Mussels Collected in Sixty 0.25-m^2 Samples in the Mississippi River, Mile 635.0, September 1988

Species	Percentage		
	Nearshore	Offshore	Total
A. imbecillis	0.34	0.34	0.36
L. fragilis	0.40	1.01	0.83
A. ligamentina	--	0.17	0.12
A. plicata	67.07	56.04	59.29
E. lineolata	--	0.17	0.12
L. ventricosa	0.40	0.84	0.71
A. grandis	--	0.17	0.12
O. olivaria	--	2.01	1.42
Q. pustulosa	2.01	5.03	4.14
Q. nodulata	1.20	0.50	0.71
Q. quadrula	2.41	2.68	2.60
T. donaciformis	1.61	0.34	0.71
T. truncata	5.62	9.40	8.28
F. flava	5.22	8.22	7.34
L. higginsi	0.40	0.17	0.24
O. reflexa	3.21	3.86	3.67
P. alatus	1.61	1.01	1.18
C. parva	4.42	1.34	2.25
L. recta	0.40	1.01	0.83
C. fluminea	0.40	--	0.12
A. confragosus	0.40	0.84	0.71
M. gigantea	2.81	3.52	3.31
L. complanata	--	0.34	0.24
P. sintoxia	--	0.17	0.12
Q. metanevra	--	0.67	0.47
S. undulatus	--	0.17	0.12
Total individuals	249	596	845
Total species	18	25	26

APPENDIX E

LENGTH-FREQUENCY HISTOGRAMS FOR BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER, JULY 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
18	|	0	0	0.00	0.00
20	|**	1	1	1.03	1.03
22	|	0	1	0.00	1.03
24	|	0	1	0.00	1.03
26	|**	1	2	1.03	2.06
28	|****	2	4	2.06	4.12
30	|**	1	5	1.03	5.15
32	|******	3	8	3.09	8.25
34	|**	1	9	1.03	9.28
36	|****	2	11	2.06	11.34
38	|**********	5	16	5.15	16.49
40	|******	3	19	3.09	19.59
42	|********	4	23	4.12	23.71
44	|****	2	25	2.06	25.77
46	|****	2	27	2.06	27.84
48	|******	3	30	3.09	30.93
50	|**	1	31	1.03	31.96
52	|******	3	34	3.09	35.05
54	|**	1	35	1.03	36.08
56	|	0	35	0.00	36.08
58	|**	1	36	1.03	37.11
60	|	0	36	0.00	37.11
62	|**	1	37	1.03	38.14
64	|******	3	40	3.09	41.24
66	|****	2	42	2.06	43.30
68	|**************	7	49	7.22	50.52
70	|********************	10	59	10.31	60.82
72	|**********	5	64	5.15	65.98
74	|************	6	70	6.19	72.16
76	|************	6	76	6.19	78.35
78	|**************	7	83	7.22	85.57
80	|************	6	89	6.19	91.75
82	|******	3	92	3.09	94.85
84	|	0	92	0.00	94.85
86	|	0	92	0.00	94.85
88	|	0	92	0.00	94.85
90	|******	3	95	3.09	97.94
92	|**	1	96	1.03	98.97
94	|	0	96	0.00	98.97
96	|**	1	97	1.03	100.00

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----+---+---+---+---+-
    2   4   6   8   10
       Percentage
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Figure E1. Shell length frequency histogram of *Amblema plicata* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
9			0	0	0.00	0.00
12	|*****	1	1	2.38	2.38
15			0	1	0.00	2.38
18			0	1	0.00	2.38
21			0	1	0.00	2.38
24			0	1	0.00	2.38
27			0	1	0.00	2.38
30			0	1	0.00	2.38
33			0	1	0.00	2.38
36	|*****	1	2	2.38	4.76
39			0	2	0.00	4.76
42			0	2	0.00	4.76
45			0	2	0.00	4.76
48	|*****	1	3	2.38	7.14
51	|*****	1	4	2.38	9.52
54	|**************	3	7	7.14	16.67
57	|**************	3	10	7.14	23.81
60	|*******************	4	14	9.52	33.33
63	|**********	2	16	4.76	38.10
66	|************************	5	21	11.90	50.00
69	|**************	3	24	7.14	57.14
72	|**************	3	27	7.14	64.29
75	|*****	1	28	2.38	66.67
78	|*****	1	29	2.38	69.05
81	|**********	2	31	4.76	73.81
84	|*****	1	32	2.38	76.19
87	|**************	3	35	7.14	83.33
90	|*******************	4	39	9.52	92.86
93			0	39	0.00	92.86
96			0	39	0.00	92.86
99	|*****	1	40	2.38	95.24
102			0	40	0.00	95.24
105	|*****	1	41	2.38	97.62
108			0	41	0.00	97.62
111			0	41	0.00	97.62
114			0	41	0.00	97.62
117	|*****	1	42	2.38	100.00
120			0	42	0.00	100.00
	----+----+----+----+----+----+				
	2 4 6 8 10 12				

<u>Percentage</u>

Figure E2. Shell length frequency histogram of *Amblema plicata* in the upper Mississippi River, RM 504.7 (Pool 14), 26 July 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0			0	0	0.00	0.00
30			0	0	0.00	0.00
31			0	0	0.00	0.00
32			0	0	0.00	0.00
33	|*	1	1	0.35	0.35
34	|*	1	2	0.35	0.70
35	|	0	2	0.00	0.70
36	|***	5	7	1.75	2.45
37	|**	3	10	1.05	3.50
38	|****	6	16	2.10	5.59
39	|****	6	22	2.10	7.69
40	|**********	14	36	4.90	12.59
41	|******	8	44	2.80	15.38
42	|**************	20	64	6.99	22.38
43	|****************	23	87	8.04	30.42
44	|***************	22	109	7.69	38.11
45	|************	17	126	5.94	44.06
46	|**********************	31	157	10.84	54.90
47	|********	11	168	3.85	58.74
48	|*************	18	186	6.29	65.03
49	|**************	20	206	6.99	72.03
50	|**********	14	220	4.90	76.92
51	|***********	16	236	5.59	82.52
52	|**********	14	250	4.90	87.41
53	|***********	16	266	5.59	93.01
54	|******	8	274	2.80	95.80
55	|******	9	283	3.15	98.95
56	|*	1	284	0.35	99.30
57	|*	1	285	0.35	99.65
58	|*	1	286	0.35	100.00
59	|	0	286	0.00	100.00
60	|	0	286	0.00	100.00
	----+---+---+---+---+--				
	2 4 6 8 10				
	Percentage				

Figure E3. Shell length frequency histogram of *Anodonta imbecillis* in the upper Mississippi River, RM 389.5 (Pool 19), 19 July 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
25	|	0	0	0.00	0.00
26	|*	1	1	0.27	0.27
27	|	0	1	0.00	0.27
28	|*	1	2	0.27	0.54
29	|	0	2	0.00	0.54
30	|	0	2	0.00	0.54
31	|	0	2	0.00	0.54
32	|	0	2	0.00	0.54
33	|*	2	4	0.54	1.08
34	|	0	4	0.00	1.08
35	|*	1	5	0.27	1.35
36	|*	2	7	0.54	1.89
37	|***	5	12	1.35	3.24
38	|***	6	18	1.62	4.86
39	|********	14	32	3.78	8.65
40	|******	11	43	2.97	11.62
41	|********	15	58	4.05	15.68
42	|**************	26	84	7.03	22.70
43	|***********************	42	126	11.35	34.05
44	|***********************	43	169	11.62	45.68
45	|*****************	32	201	8.65	54.32
46	|***********************	42	243	11.35	65.68
47	|*******************	35	278	9.46	75.14
48	|***************	28	306	7.57	82.70
49	|************	23	329	6.22	88.92
50	|********	15	344	4.05	92.97
51	|********	14	358	3.78	96.76
52	|****	7	365	1.89	98.65
53	|*	1	366	0.27	98.92
54	|*	2	368	0.54	99.46
55	|*	1	369	0.27	99.73
56	|	0	369	0.00	99.73
57	|	0	369	0.00	99.73
58	|	0	369	0.00	99.73
59	|	0	369	0.00	99.73
60	|	0	369	0.00	99.73
61	|	0	369	0.00	99.73
62	|	0	369	0.00	99.73
63	|	0	369	0.00	99.73
64	|	0	369	0.00	99.73
65	|	0	369	0.00	99.73
66	|	0	369	0.00	99.73
67	|	0	369	0.00	99.73
68	|*	1	370	0.27	100.00
	----+---+---+---+---+---				
	2 4 6 8 10				
	Percentage				

Figure E4. Shell length frequency histogram of *Anodonta imbecillis* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
4		0	0	0.00	0.00
8		0	0	0.00	0.00
12		0	0	0.00	0.00
16		0	0	0.00	0.00
20		0	0	0.00	0.00
24	***************************	14	14	26.92	26.92
28	***********************************	18	32	34.62	61.54
32	******	3	35	5.77	67.31
36	****	2	37	3.85	71.15
40	**********	5	42	9.62	80.77
44	****	2	44	3.85	84.62
48	******	3	47	5.77	90.38
52	****	2	49	3.85	94.23
56	**	1	50	1.92	96.15
60		0	50	0.00	96.15
64	****	2	52	3.85	100.00
68		0	52	0.00	100.00
72		0	52	0.00	100.00

```
    ----+----+----+----+----+----+----+
        5   10   15   20   25   30   35
```

Percentage

Figure E5. Shell length frequency histogram of *Elipsaria lineolatas* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

```
Shell Length                                           Cumulative      Cumulative
                                                  Freq    Freq  Percent  Percent
            |
     0      |                                        0       0     0.00     0.00
     8      |                                        0       0     0.00     0.00
    16      |                                        0       0     0.00     0.00
    20      |                                        0       0     0.00     0.00
    24      |***                                     1       1     1.49     1.49
    28      |                                        0       1     0.00     1.49
    32      |                                        0       1     0.00     1.49
    36      |***                                     1       2     1.49     2.99
    40      |******                                  2       4     2.99     5.97
    44      |                                        0       4     0.00     5.97
    48      |***                                     1       5     1.49     7.46
    52      |*********                               3       8     4.48    11.94
    56      |******************                      6      14     8.96    20.90
    60      |******************                      6      20     8.96    29.85
    64      |*********************                   7      27    10.45    40.30
    68      |************************************   12      39    17.91    58.21
    72      |*********                               3      42     4.48    62.69
    76      |******************                      6      48     8.96    71.64
    80      |*********                               3      51     4.48    76.12
    84      |************                            4      55     5.97    82.09
    88      |*********                               3      58     4.48    86.57
    92      |******                                  2      60     2.99    89.55
    96      |************                            4      64     5.97    95.52
   100      |***                                     1      65     1.49    97.01
   104      |******                                  2      67     2.99   100.00
   108      |                                        0      67     0.00   100.00
            ----+---+---+---+---+---+---+---+---+
                2   4   6   8  10  12  14  16  18

                       Percentage
```

Figure E6. Shell length frequency histogram of *Leptodea fragilis* in the upper Mississippi River, RM 389.5 (Pool 19), 19 July 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
4		0	0	0.00	0.00
8		0	0	0.00	0.00
12	*	1	1	0.67	0.67
16	*	1	2	0.67	1.34
20	****	3	5	2.01	3.36
24	***	2	7	1.34	4.70
28	***	2	9	1.34	6.04
32	***	2	11	1.34	7.38
36	*	1	12	0.67	8.05
40	***	2	14	1.34	9.40
44		0	14	0.00	9.40
48	*******	5	19	3.36	12.75
52	*****************	13	32	8.72	21.48
56	************	9	41	6.04	27.52
60	*****************	13	54	8.72	36.24
64	*******************	14	68	9.40	45.64
68	***************************************	29	97	19.46	65.10
72	****************	12	109	8.05	73.15
76	***************	11	120	7.38	80.54
80	***********	8	128	5.37	85.91
84	********	6	134	4.03	89.93
88	*******	5	139	3.36	93.29
92	*********	7	146	4.70	97.99
96		0	146	0.00	97.99
100	***	2	148	1.34	99.33
104		0	148	0.00	99.33
108	*	1	149	0.67	100.00
112		0	149	0.00	100.00
116		0	149	0.00	100.00
120		0	149	0.00	100.00
	2 4 6 8 10 12 14 16 18				

Percentage

Figure E7. Shell length frequency histogram of *Leptodea fragilis* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

```
Shell Length                                      Cumulative    Cumulative
                                            Freq  Freq  Percent  Percent
          |
   12     |                                   0     0     0.00     0.00
   15     |                                   0     0     0.00     0.00
   18     |                                   0     0     0.00     0.00
   21     |***************                    2     2     7.41     7.41
   24     |***************                    2     4     7.41    14.81
   27     |*******                            1     5     3.70    18.52
   30     |*******                            1     6     3.70    22.22
   33     |**********************             3     9    11.11    33.33
   36     |*************************************  5    14    18.52    51.85
   39     |***************                    2    16     7.41    59.26
   42     |*************************************  5    21    18.52    77.78
   45     |*******                            1    22     3.70    81.48
   48     |**********************             3    25    11.11    92.59
   51     |                                   0    25     0.00    92.59
   54     |                                   0    25     0.00    92.59
   57     |*******                            1    26     3.70    96.30
   60     |                                   0    26     0.00    96.30
   63     |                                   0    26     0.00    96.30
   66     |                                   0    26     0.00    96.30
   69     |                                   0    26     0.00    96.30
   72     |                                   0    26     0.00    96.30
   75     |                                   0    26     0.00    96.30
   78     |                                   0    26     0.00    96.30
   81     |                                   0    26     0.00    96.30
   84     |                                   0    26     0.00    96.30
   87     |                                   0    26     0.00    96.30
   90     |                                   0    26     0.00    96.30
   93     |*******                            1    27     3.70   100.00
   96     |                                   0    27     0.00   100.00
   99     |                                   0    27     0.00   100.00
          ----+---+---+---+---+---+---+---+---+-
              2   4   6   8  10  12  14  16  18

                      Percentage
```

Figure E8. Shell length frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 504.7 (Pool 14), 26 July 1988

```
Shell Length                                             Cumulative         Cumulative
                                                  Freq   Freq    Percent    Percent
           |
   0       |                                         0      0      0.00       0.00
  36       |                                         0      0      0.00       0.00
  40       |                                         0      0      0.00       0.00
  44       |*****                                    1      1      2.63       2.63
  48       |                                         0      1      0.00       2.63
  52       |                                         0      1      0.00       2.63
  56       |                                         0      1      0.00       2.63
  60       |***********                              2      3      5.26       7.89
  64       |*****                                    1      4      2.63      10.53
  68       |****************                         3      7      7.89      18.42
  72       |****************                         3     10      7.89      26.32
  76       |**************************               5     15     13.16      39.47
  80       |********************************         6     21     15.79      55.26
  84       |*************************************    7     28     18.42      73.68
  88       |********************************         6     34     15.79      89.47
  92       |***********                              2     36      5.26      94.74
  96       |*****                                    1     37      2.63      97.37
 100       |                                         0     37      0.00      97.37
 104       |*****                                    1     38      2.63     100.00
 108       |                                         0     38      0.00     100.00
 112       |                                         0     38      0.00     100.00
 116       |                                         0     38      0.00     100.00
           ----+---+---+---+---+---+---+---+---+-
               2   4   6   8  10  12  14  16  18

                        Percentage
```

Figure E9. Shell length frequency histogram of *Potamilus alata* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

```
Shell Length                                           Cumulative      Cumulative
                                                Freq   Freq   Percent   Percent
              |
      0       |                                   0       0     0.00      0.00
     10       |                                   0       0     0.00      0.00
     12       |****                               1       1     0.99      0.99
     14       |                                   0       1     0.00      0.99
     16       |********                           2       3     1.98      2.97
     18       |************                       3       6     2.97      5.94
     20       |************************************ 9    15     8.91     14.85
     22       |********************               5      20     4.95     19.80
     24       |                                   0      20     0.00     19.80
     26       |********************               5      25     4.95     24.75
     28       |****************                   4      29     3.96     28.71
     30       |********                           2      31     1.98     30.69
     32       |****                               1      32     0.99     31.68
     34       |************************           6      38     5.94     37.62
     36       |************************************ 9    47     8.91     46.53
     38       |****************                   4      51     3.96     50.50
     40       |************                       3      54     2.97     53.47
     42       |****************                   4      58     3.96     57.43
     44       |********************               5      63     4.95     62.38
     46       |********************               5      68     4.95     67.33
     48       |********                           2      70     1.98     69.31
     50       |****************                   4      74     3.96     73.27
     52       |************************           6      80     5.94     79.21
     54       |************                       3      83     2.97     82.18
     56       |********                           2      85     1.98     84.16
     58       |********************************   8      93     7.92     92.08
     60       |                                   0      93     0.00     92.08
     62       |********                           2      95     1.98     94.06
     64       |********                           2      97     1.98     96.04
     66       |                                   0      97     0.00     96.04
     68       |                                   0      97     0.00     96.04
     70       |****                               1      98     0.99     97.03
     72       |********                           2     100     1.98     99.01
     74       |                                   0     100     0.00     99.01
     76       |****                               1     101     0.99    100.00
     78       |                                   0     101     0.00    100.00
     80       |                                   0     101     0.00    100.00
              ----+---+---+---+---+---+---+---+---+
                  1   2   3   4   5   6   7   8   9

                          Percentage
```

Figure E10. Shell length frequency histogram of *Quadrula pustulosa* in the upper Mississippi River, RM 433.3 (Pool 18), 23 July 1988

```
Shell Length
                                            Cumulative   Cumulative
                                      Freq  Freq  Percent  Percent
           |
     0     |                             0     0     0.00     0.00
     2     |                             0     0     0.00     0.00
     4     |                             0     0     0.00     0.00
     6     |                             0     0     0.00     0.00
     8     |                             0     0     0.00     0.00
    10     |***                          1     1     1.61     1.61
    12     |                             0     1     0.00     1.61
    14     |                             0     1     0.00     1.61
    16     |                             0     1     0.00     1.61
    18     |                             0     1     0.00     1.61
    20     |***                          1     2     1.61     3.23
    22     |******                       2     4     3.23     6.45
    24     |******                       2     6     3.23     9.68
    26     |**********                   3     9     4.84    14.52
    28     |**********                   3    12     4.84    19.35
    30     |**********                   3    15     4.84    24.19
    32     |*******************          6    21     9.68    33.87
    34     |****************             5    26     8.06    41.94
    36     |******                       2    28     3.23    45.16
    38     |*************                4    32     6.45    51.61
    40     |**********                   3    35     4.84    56.45
    42     |*************                4    39     6.45    62.90
    44     |***                          1    40     1.61    64.52
    46     |                             0    40     0.00    64.52
    48     |*************                4    44     6.45    70.97
    50     |***                          1    45     1.61    72.58
    52     |******                       2    47     3.23    75.81
    54     |**********                   3    50     4.84    80.65
    56     |******                       2    52     3.23    83.87
    58     |**********************       7    59    11.29    95.16
    60     |***                          1    60     1.61    96.77
    62     |                             0    60     0.00    96.77
    64     |***                          1    61     1.61    98.39
    66     |***                          1    62     1.61   100.00
           ----+---+---+---+---+---
               2   4   6   8   10

              Percentage
```

Figure E11. Shell length frequency histogram of *Quadrula pustulosa* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

```
Shell Length                                          Cumulative      Cumulative
                                                Freq  Freq   Percent  Percent
          |
    0     |                                       0     0      0.00      0.00
   16     |                                       0     0      0.00      0.00
   18     |******                                 1     1      2.86      2.86
   20     |                                       0     1      0.00      2.86
   22     |******                                 1     2      2.86      5.71
   24     |                                       0     2      0.00      5.71
   26     |                                       0     2      0.00      5.71
   28     |                                       0     2      0.00      5.71
   30     |                                       0     2      0.00      5.71
   32     |                                       0     2      0.00      5.71
   34     |*****************                      3     5      8.57     14.29
   36     |                                       0     5      0.00     14.29
   38     |******                                 1     6      2.86     17.14
   40     |                                       0     6      0.00     17.14
   42     |*****************                      3     9      8.57     25.71
   44     |******                                 1    10      2.86     28.57
   46     |***********                            2    12      5.71     34.29
   48     |**********************                 4    16     11.43     45.71
   50     |****************************           5    21     14.29     60.00
   52     |*****************                      3    24      8.57     68.57
   54     |**********************                 4    28     11.43     80.00
   56     |                                       0    28      0.00     80.00
   58     |******                                 1    29      2.86     82.86
   60     |                                       0    29      0.00     82.86
   62     |                                       0    29      0.00     82.86
   64     |                                       0    29      0.00     82.86
   66     |******                                 1    30      2.86     85.71
   68     |******                                 1    31      2.86     88.57
   70     |******                                 1    32      2.86     91.43
   72     |******                                 1    33      2.86     94.29
   74     |                                       0    33      0.00     94.29
   76     |                                       0    33      0.00     94.29
   78     |******                                 1    34      2.86     97.14
   80     |                                       0    34      0.00     97.14
   82     |                                       0    34      0.00     97.14
   84     |******                                 1    35      2.86    100.00
   86     |                                       0    35      0.00    100.00
          ----+---+---+---+---+---+---+-
              2   4   6   8  10  12  14

                    Percentage
```

Figure E12. Shell length frequency histogram of *Quadrula quadrula* in the upper Mississippi River, RM 433.3 (Pool 18), 23 July 1988

```
Shell Length                                  Cumulative        Cumulative
                                         Freq  Freq   Percent   Percent
             |
     0       |                             0     0      0.00      0.00
    12       |                             0     0      0.00      0.00
    13       |**                           1     1      1.00      1.00
    14       |**********                   5     6      5.00      6.00
    15       |******                       3     9      3.00      9.00
    16       |****                         2    11      2.00     11.00
    17       |**********                   5    16      5.00     16.00
    18       |************                 6    22      6.00     22.00
    19       |****************             8    30      8.00     30.00
    20       |****************************14    44     14.00     44.00
    21       |****************************14    58     14.00     58.00
    22       |******************************15  73     15.00     73.00
    23       |************                 6    79      6.00     79.00
    24       |**********************      11    90     11.00     90.00
    25       |********                     4    94      4.00     94.00
    26       |                             0    94      0.00     94.00
    27       |********                     4    98      4.00     98.00
    28       |                             0    98      0.00     98.00
    29       |                             0    98      0.00     98.00
    30       |                             0    98      0.00     98.00
    31       |**                           1    99      1.00     99.00
    32       |                             0    99      0.00     99.00
    33       |                             0    99      0.00     99.00
              ----+---+---+---+---+---+---+--
                  2   4   6   8  10  12  14

                        Percentage
```

Figure E13. Shell length frequency histogram of *Truncilla donaciformis* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

```
Shell Length                                         Cumulative      Cumulative
                                              Freq   Freq   Percent   Percent
          |
   0      |                                      0      0      0.00      0.00
   2      |                                      0      0      0.00      0.00
   4      |                                      0      0      0.00      0.00
   6      |                                      0      0      0.00      0.00
   8      |                                      0      0      0.00      0.00
  10      |                                      0      0      0.00      0.00
  12      |                                      0      0      0.00      0.00
  14      |*******                               1      1      3.70      3.70
  16      |                                      0      1      0.00      3.70
  18      |***************                       2      3      7.41     11.11
   :      |***************                       2      5      7.41     18.52
          |**********************                3      8     11.11     29.63
          '                                      0      8      0.00     29.63
   6                                             0      8      0.00     29.63
  28      |                                      0      8      0.00     29.63
  30      |*******                               1      9      3.70     33.33
  32      |*******                               1     10      3.70     37.04
  34      |******************************        4     14     14.81     51.85
  36      |*************************************  5    19     18.52     70.37
  38      |**********************                3     22     11.11     81.48
  40      |***************                       2     24      7.41     88.89
  42      |*******                               1     25      3.70     92.59
  44      |*******                               1     26      3.70     96.30
  46      |*******                               1     27      3.70    100.00
  48      |                                      0     27      0.00    100.00
          ----+---+---+---+---+---+---+---+---+-
              2   4   6   8  10  12  14  16  18
                      Percentage
```

Figure E14. Shell length frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 299.6 (Pool 20), 20 July 1988

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0	|	0	0	0.00	0.00
10	|	0	0	0.00	0.00
12	|***	2	2	1.30	1.30
14	|	0	2	0.00	1.30
16	|****	3	5	1.95	3.25
18	|********	6	11	3.90	7.14
20	|********	6	17	3.90	11.04
22	|*****	4	21	2.60	13.64
24	|****	3	24	1.95	15.58
26	|***	2	26	1.30	16.88
28	|********	6	32	3.90	20.78
30	|************	9	41	5.84	26.62
32	|********	6	47	3.90	30.52
34	|**************	11	58	7.14	37.66
36	|*****************	13	71	8.44	46.10
38	|**************************	20	91	12.99	59.09
40	|**********	8	99	5.19	64.29
42	|*******************	15	114	9.74	74.03
44	|**************************	20	134	12.99	87.01
46	|**************	11	145	7.14	94.16
48	|********	6	151	3.90	98.05
50	|***	2	153	1.30	99.35
52	|*	1	154	0.65	100.00
54	|	0	154	0.00	100.00
56	|	0	154	0.00	100.00

```
----+---+---+---+---+---+--
    2   4   6   8   10  12
```

Percentage

Figure E15. Shell length frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 433.3 (Pool 18), 23 July 1988

```
Shell Length                                              Cumulative     Cumulative
                                                      Freq  Freq  Percent  Percent
          |
     0    |                                              0     0     0.00     0.00
     2    |                                              0     0     0.00     0.00
     4    |                                              0     0     0.00     0.00
     6    |                                              0     0     0.00     0.00
     8    |                                              0     0     0.00     0.00
    10    |                                              0     0     0.00     0.00
    12    |                                              0     0     0.00     0.00
    14    |                                              0     0     0.00     0.00
    16    |                                              0     0     0.00     0.00
    18    |***                                           3     3     1.64     1.64
    20    |****                                          4     7     2.19     3.83
    22    |********                                      7    14     3.83     7.65
    24    |*******                                       6    20     3.28    10.93
    26    |*********                                     8    28     4.37    15.30
    28    |*******************                          17    45     9.29    24.59
    30    |*************************************        34    79    18.58    43.17
    32    |************************                     22   101    12.02    55.19
    34    |******************************               27   128    14.75    69.95
    36    |***************************                  25   153    13.66    83.61
    38    |*****************                            16   169     8.74    92.35
    40    |********                                      7   176     3.83    96.17
    42    |*                                             1   177     0.55    96.72
    44    |***                                           3   180     1.64    98.36
    46    |**                                            2   182     1.09    99.45
    48    |                                              0   182     0.00    99.45
    50    |*                                             1   183     0.55   100.00
    52    |                                              0   183     0.00   100.00
    54    |                                              0   183     0.00   100.00
          ----+---+---+---+---+---+---+---+---+-
              2   4   6   8  10  12  14  16  18

                     Percentage
```

Figure E16. Shell length frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 450.4 (Pool 17), 25 July 1988

```
Shell Length                                           Cumulative   Cumulative
                                          Freq   Freq    Percent      Percent
          |
    0     |                                  0      0       0.00         0.00
    2     |                                  0      0       0.00         0.00
    4     |                                  0      0       0.00         0.00
    6     |                                  0      0       0.00         0.00
    8     |                                  0      0       0.00         0.00
   10     |                                  0      0       0.00         0.00
   12     |****                              1      1       2.04         2.04
   14     |                                  0      1       0.00         2.04
   16     |                                  0      1       0.00         2.04
   18     |                                  0      1       0.00         2.04
   20     |****                              1      2       2.04         4.08
   22     |********                          2      4       4.08         8.16
   24     |****************                  4      8       8.16        16.33
   26     |************                      3     11       6.12        22.45
   28     |************                      3     14       6.12        28.57
   30     |****************************      7     21      14.29        42.86
   32     |****************************      7     28      14.29        57.14
   34     |********************              5     33      10.20        67.35
   36     |************                      3     36       6.12        73.47
   38     |********************              5     41      10.20        83.67
   40     |************                      3     44       6.12        89.80
   42     |****                              1     45       2.04        91.84
   44     |************                      3     48       6.12        97.96
   46     |****                              1     49       2.04       100.00
   48     |                                  0     49       0.00       100.00
          ----+---+---+---+---+---+---+-
              2   4   6   8  10  12  14

                  Percentage
```

Figure E17. Shell length frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 504.7 (Pool 14), 26 July 1988

APPENDIX F

SHELL MORPHOMETRICS FOR *AMBLEMA PLICATA*
UPPER MISSISSIPPI RIVER, 1988

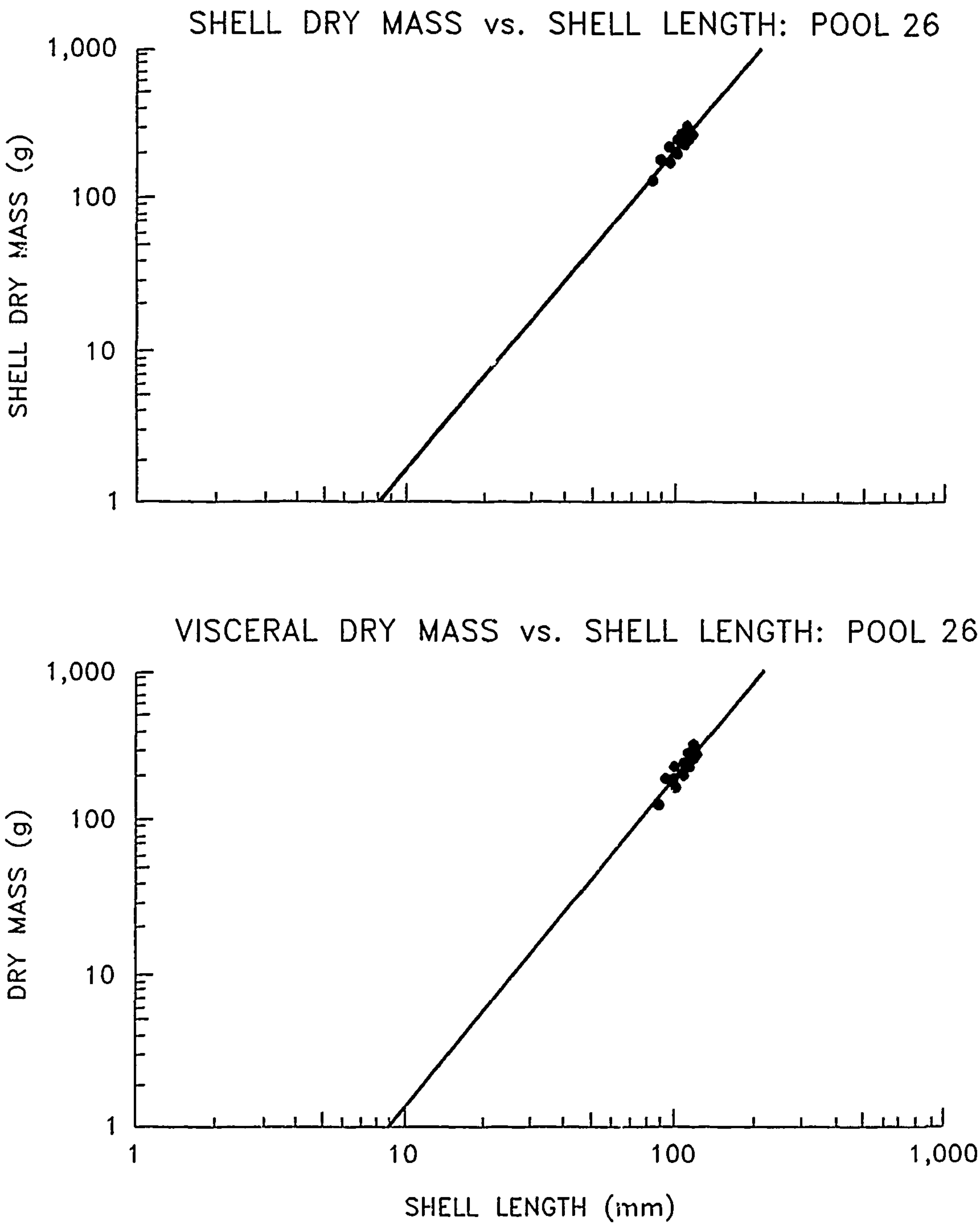
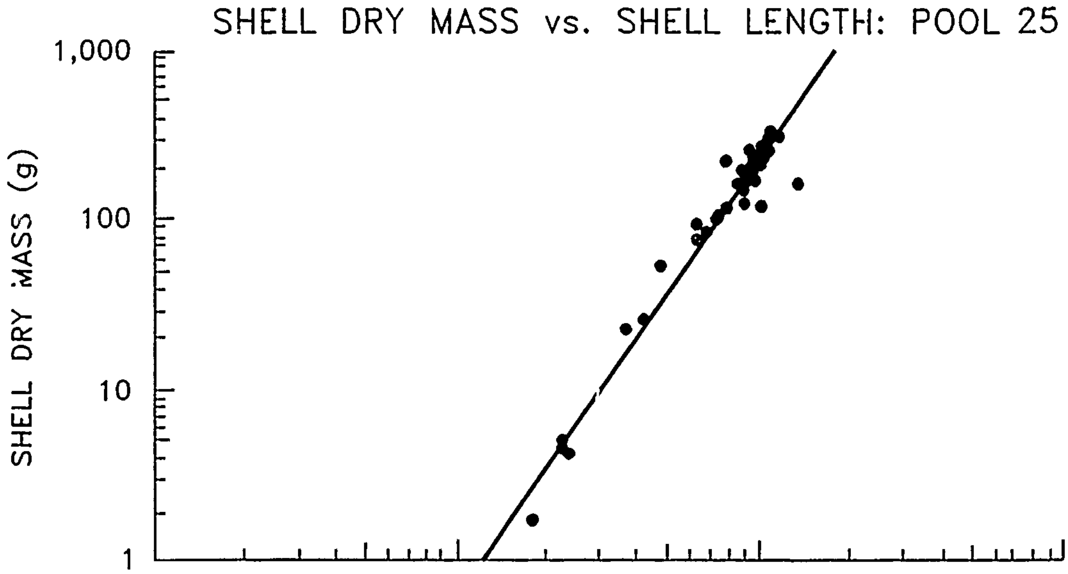


Figure F1. Shell morphometrics for Pool 26



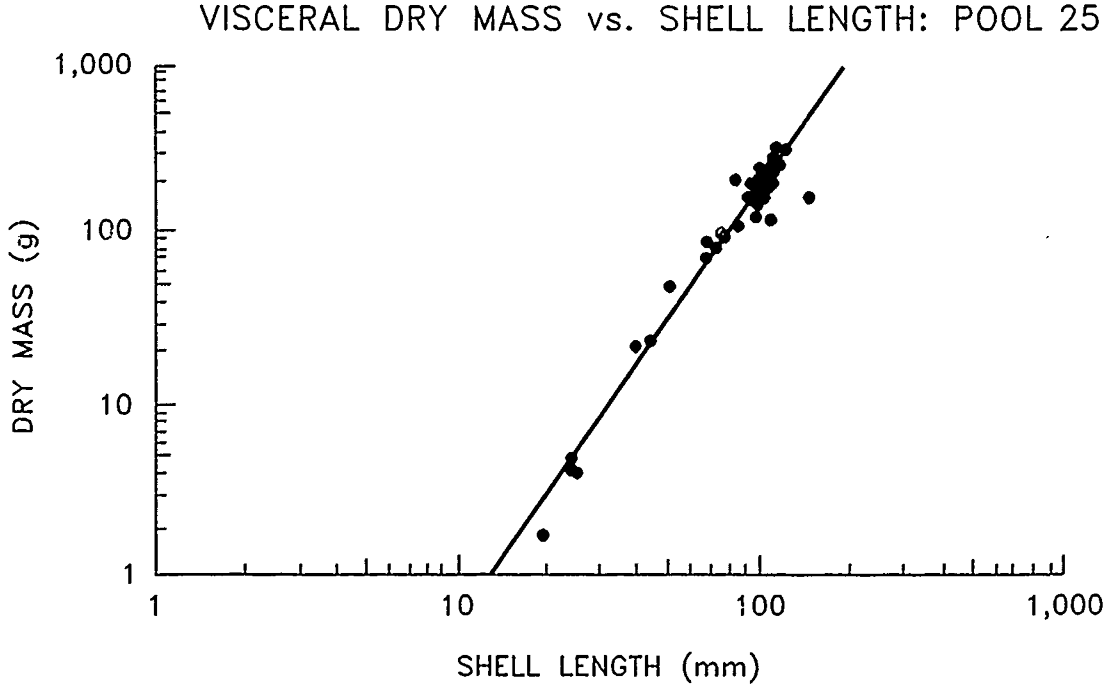


Figure F2. Shell morphometrics for Pool 25

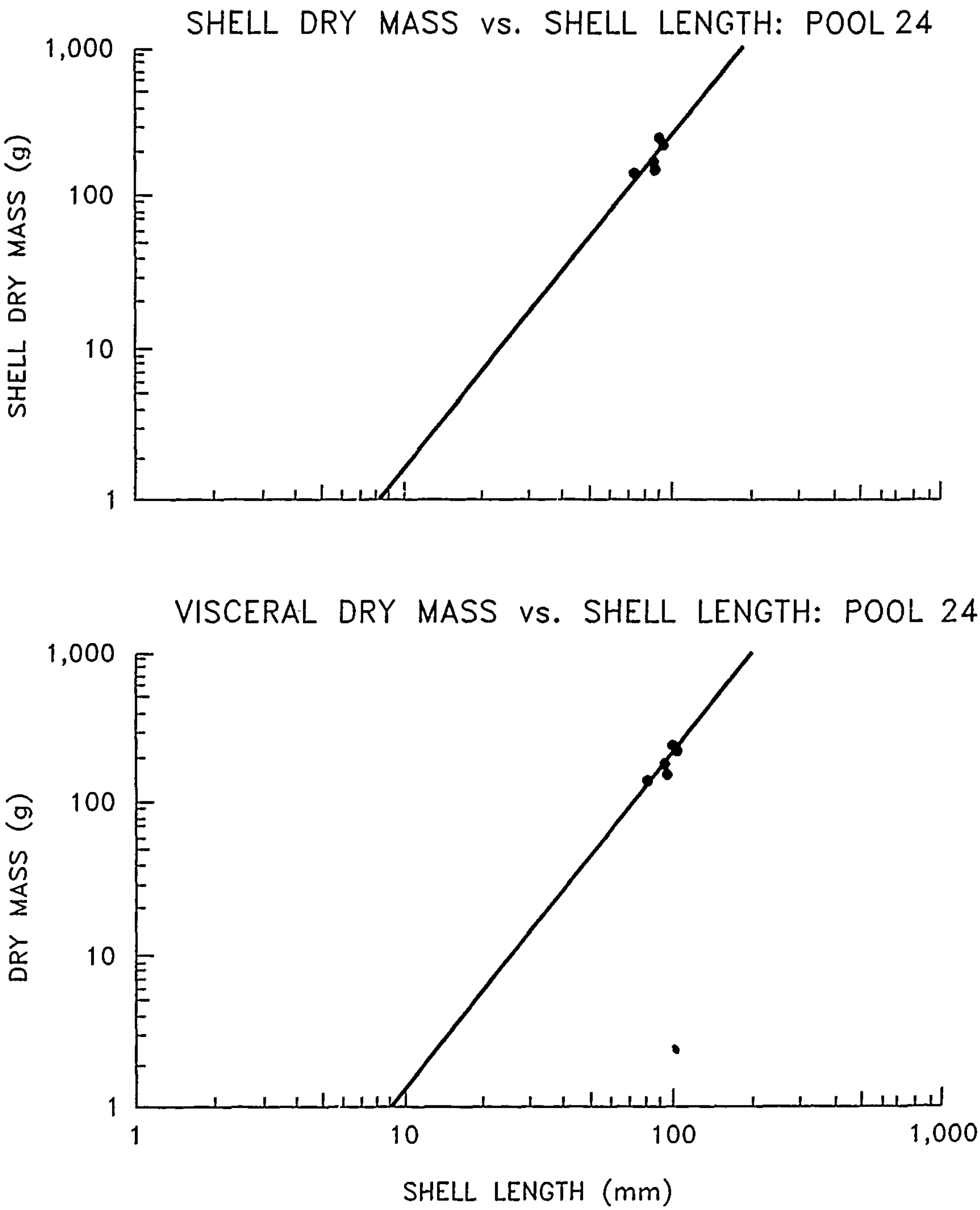


Figure F3. Shell morphometrics for Pool 24

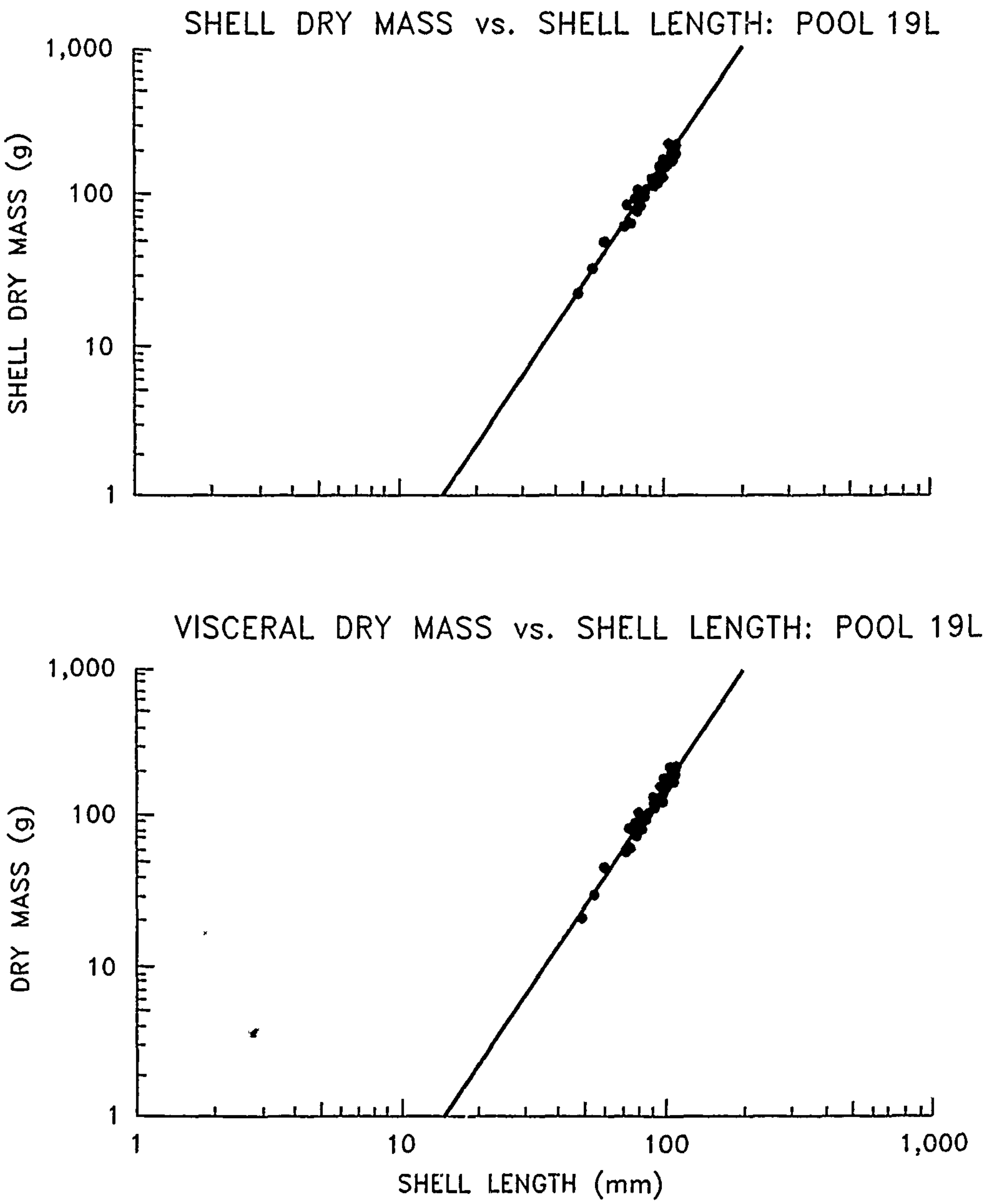


Figure F4. Shell morphometrics for Pool 19L

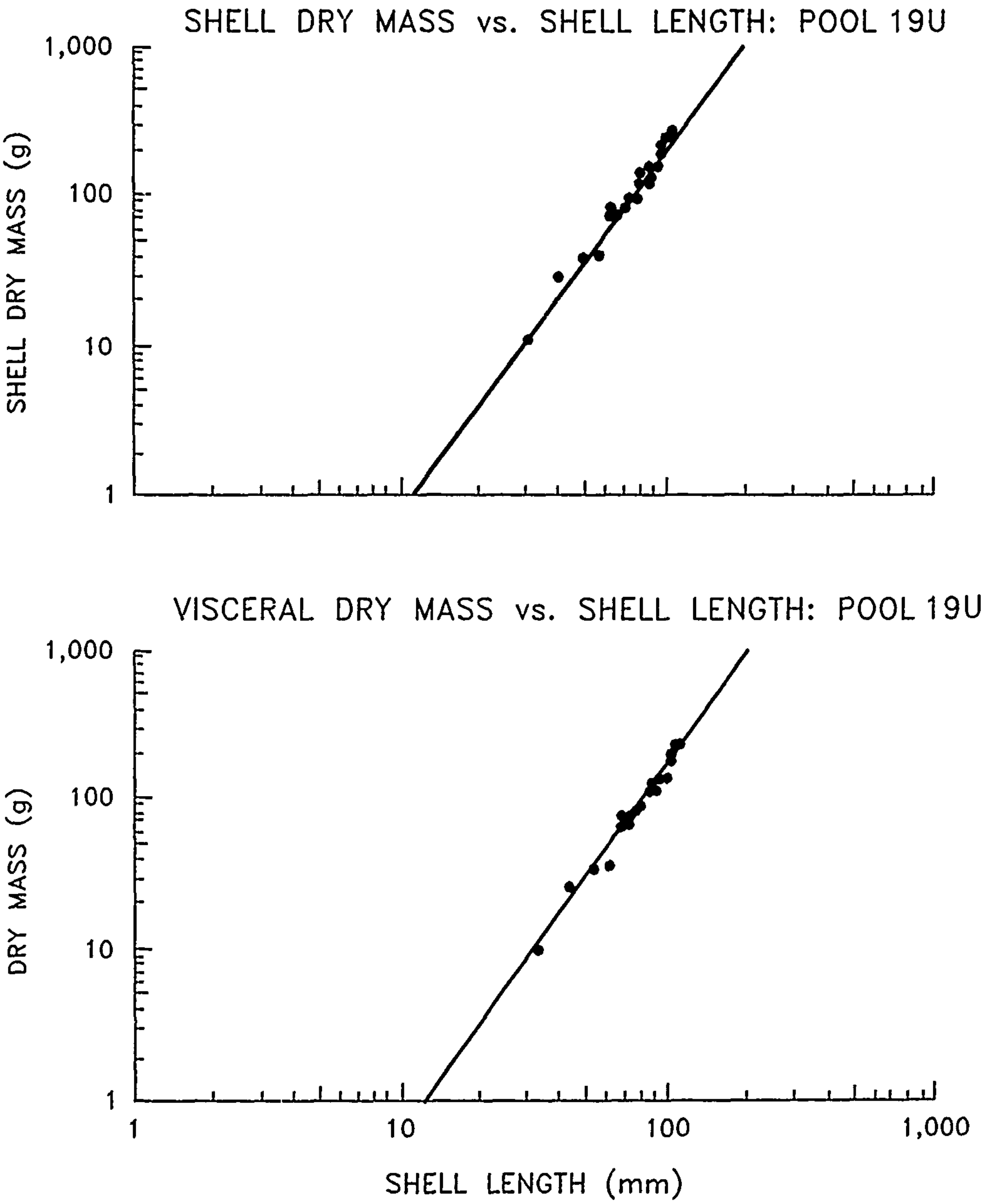


Figure F5. Shell morphometrics for Pool 19U

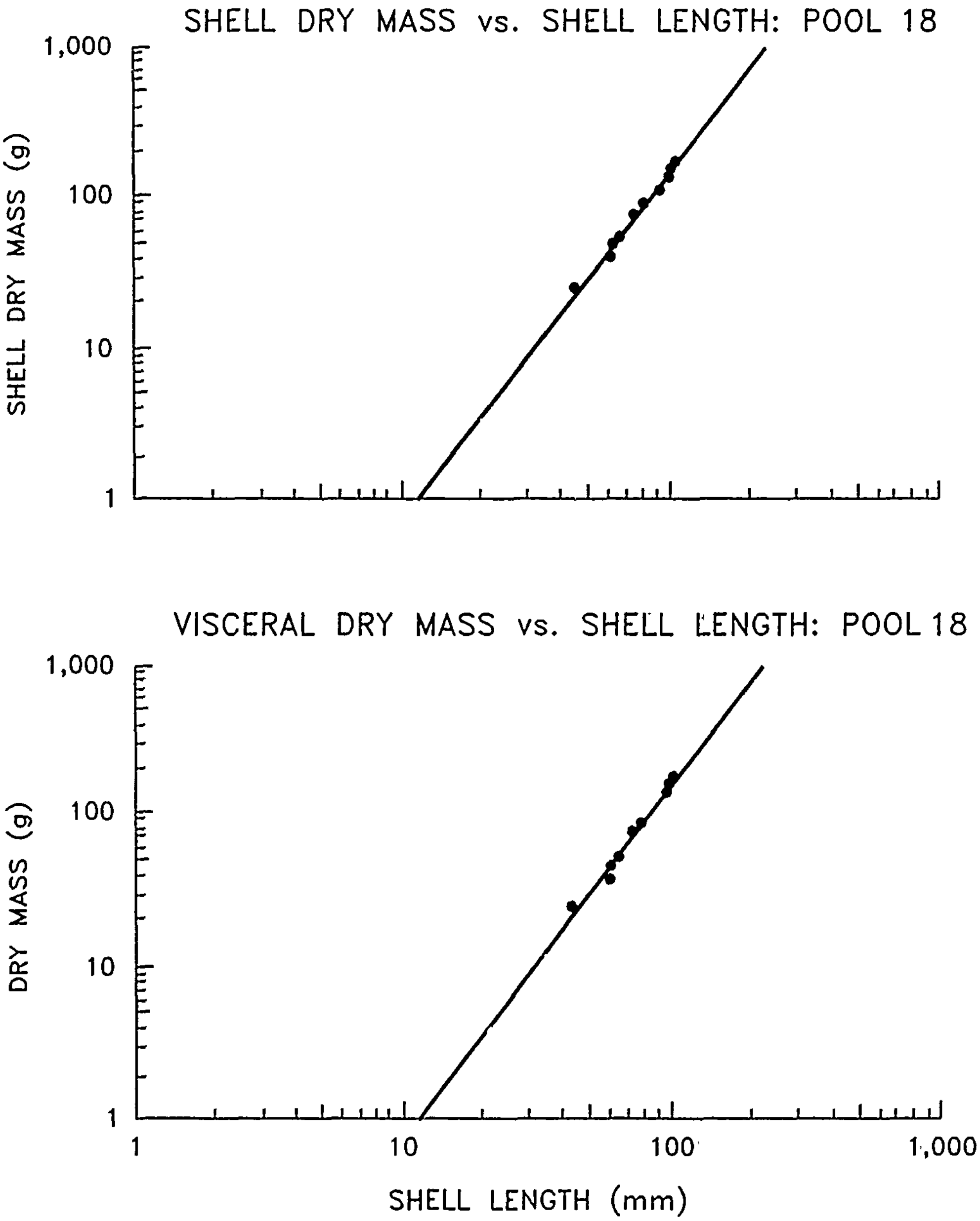


Figure F6. Shell morphometrics for Pool 18

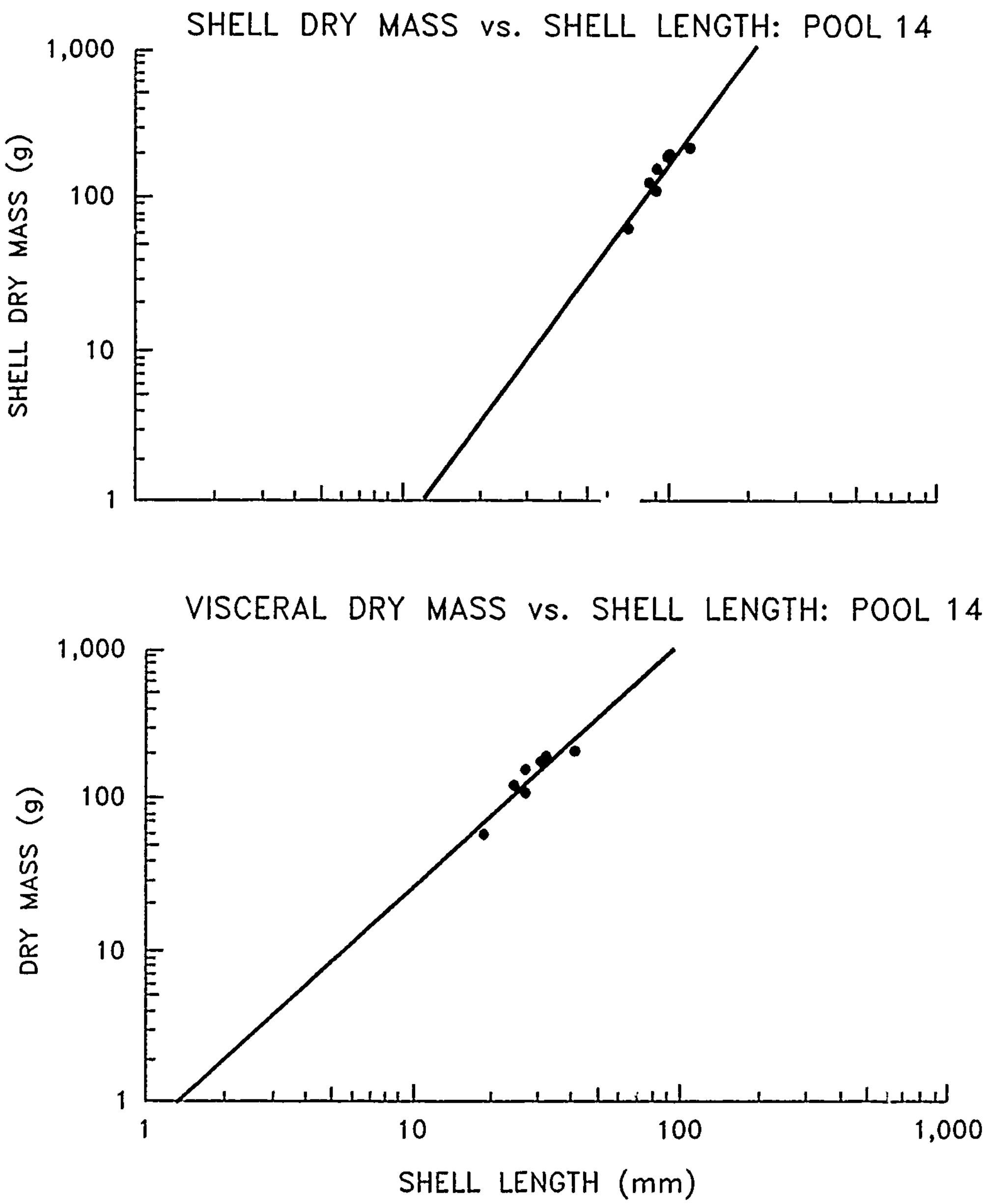


Figure F7. Shell morphometrics for Pool 14

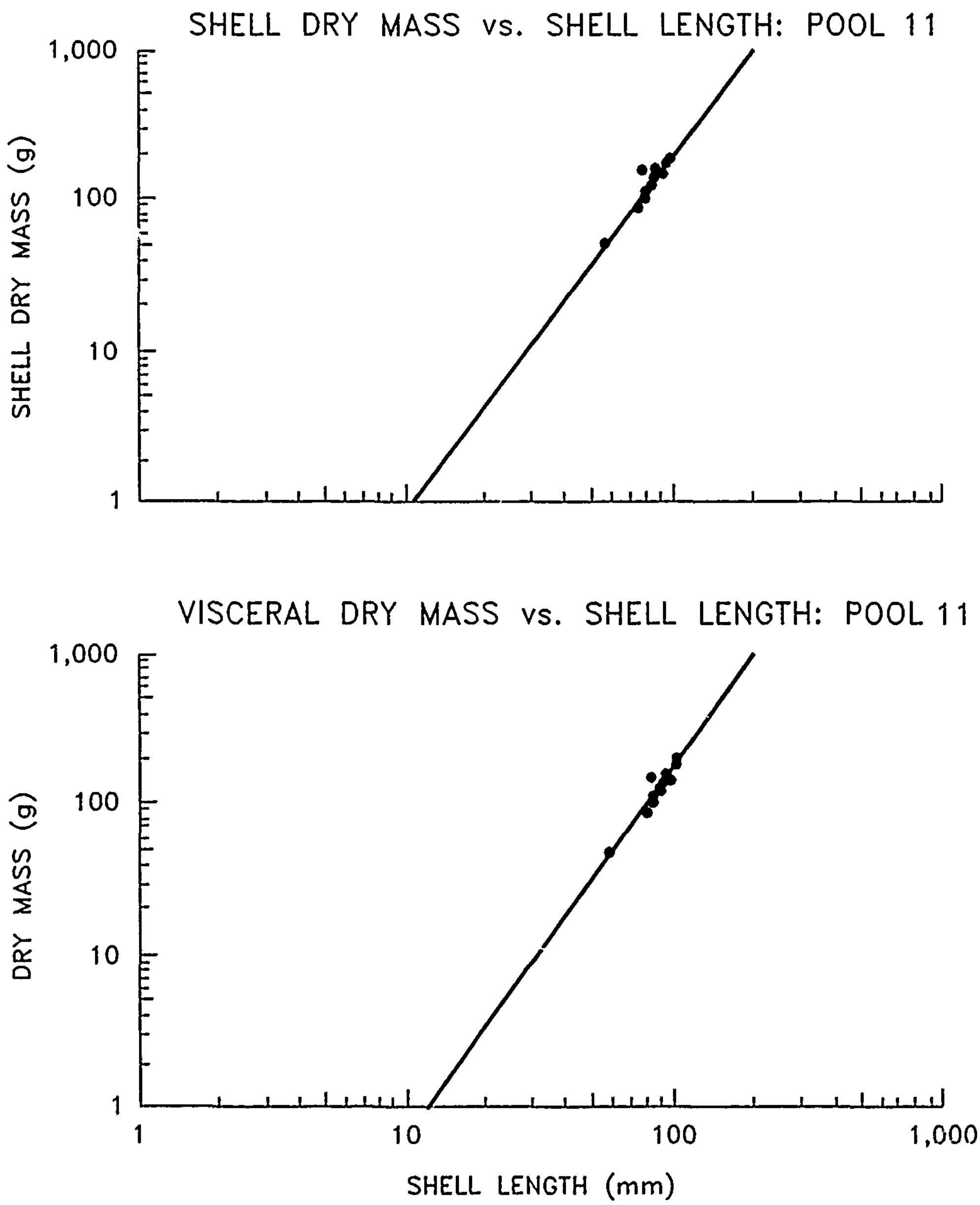


Figure F8. Shell morphometrics for Pool 11